

## ATTACHMENT 2 - INFORMATION DOCUMENT REGISTER

**FLYING FISH COVE LANDSLIDE MITIGATION – ARUP / STAGE 1 CONTRACTOR RED LINE MARK UP**

Item	DOCUMENT	Date	Rev
1	LANDSLIDE MITIGATION CONCEPT DESIGN REPORT - FLYING FISH COVE, CHRISTMAS ISLAND	15/07/2019	Final
2	STAGE 1 LANDSLIDE MITIGATION - AS INSTALLED DRAWING (REDLINE MARK UP)	2022	A
	C37137-03 LOCATION OF HV AT MARINE 1		
	CI-EW-03 TPC ACCESS PATH DETAILS [CIC BARRIER TELSTRA POWER CABLE LOCATION]		
	CI-CL-01 CONTROL LINE SETOUT		
	CI-DD-01 BOAT CLUB, MARINE 2 & MARINE 1 - DEMOLITION PLAN		
	CI-DD-02 CHRISTMAS ISLAND CLUB - DEMOLITION PLAN		
	CI-EF-01 EXISTING FEATURES - SITE PLAN		
	CI-EW-01 ACCESS PATH DETAILS - SHEET 1 [ACCESS PATH BC M2]		
	CI-EW-02 ACCESS PATH DETAILS - TYPICAL SECTIONS		
	CI-EW-03 ACCESS PATH DETAILS - SHEET 2 [CIC DRAPED MESH PART 2 REV 1]		
	CI-EW-03 ACCESS PATH DETAILS - SHEET 2 [CIC GABION AND GATE PART 1]		
	CI-EW-04 ACCESS PATH DETAILS - SHEET 3 [ACCESS PATH M2 M1]		
	CI-GA-01 BOAT CLUB - GENERAL ARRANGEMENT		
	CI-GA-02 MARINE 2 - GENERAL ARRANGEMENT		
	CI-GA-03 MARINE 1- GENERAL ARRANGEMENT		
	CI-GA-04 CHRISTMAS ISLAND CLUB - GENERAL ARRANGEMENT		
	CI-GD-01 TYPICAL DETAILS - SHEET 1		
	CI-GD-02 TYPICAL DETAILS - SHEET 2		
	CI-GD-03 TYPICAL DETAILS - SHEET 3		
	CI-GD-04 TYPICAL DETAILS - SHEET 4		
	CI-GD-05 TYPICAL DETAILS - SHEET 5		
	CI-GD-06 TYPICAL DETAILS - SHEET 6		
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	CI-GD-08 TYPICAL DETAILS - SHEET 8		
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	CI-GD-11 TYPICAL DETAILS - SHEET 11		
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	CI-LR-01 LANDSCAPE TREATMENT AREAS - SHEET 1		
	CI-LR-02 LANDSCAPE TREATMENT AREAS - SHEET 2		
3	STAGE 2 LANDSLIDE MITIGATION - ISSUED FOR TENDER DRAWINGS (DWG INCLUDING XREFS)	2022	
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**FLYING FISH COVE QUANTITATIVE LANDSLIDE RISK ASSESSMENT - GHD**

Item	DOCUMENT	Date	Rev
1	FLYING FISH COVE, CHRISTMAS ISLAND - QUANTITATIVE LANDSLIDE RISK ASSESSMENT	01/07/18	2

**CHRISTMAS ISLAND STORMWATER, LANDSLIDE AND ROCKFALL MITIGATION - DITRDCA**

Item	DOCUMENT	Date	Rev
1	CI SLR MITIGATION PROJECT - PRE-TENDER INDUSTRY BRIEFING	20/10/24	

Australian Government Department of Infrastructure, Transport, Cities and Regional Development (DITCRD)

Report Ref: 268575-00 | Final Issue 15 July 2019

# Landslide Mitigation Concept Design Report

## Flying Fish Cove, Christmas Island

# ARUP



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Department of Infrastructure,  
Transport, Cities & Regional  
Development

**Flying Fish Cove, Christmas  
Island**

Landslide Mitigation

Report Ref: 268575

Final | 15 July 2019

This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Job number 268575-00

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## Executive Summary

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Arup were engaged by Department of Infrastructure, Transport, Cities and Regional Development (DITCRD) to develop 30% (concept) design for debris flow and rockfall mitigation measures at Flying Fish Cove, Christmas Island.

GHD prepared a Quantitative Landslide Risk Assessment (QRA) for Flying Fish Cove and found that the risk from debris flows exceeded tolerable limits for risk of loss of life at three individual sites. After a review of the QRA, Arup carried out a landslide mitigation measures options assessment for these select sites. DITCRD selected debris flow / rockfall fences as the preferred option for mitigation.

Debris flow and rockfall modelling has been carried out to inform sizing and conceptual design of the fences. The modelling has shown that the proposed fences would reduce the risk of loss of life to below tolerable limits.

Landslide Mitigation Concept Design

# Introduction

# 1 Introduction

Arup has been engaged by the Department of Infrastructure, Transport, Cities and Regional Development (DITCRD, previously Department of Regional Development and Cities (DIRDC)) to develop conceptual design debris flow models and rockfall mitigation measures at Flying Fish Cove, Christmas Island.

## 1.1 Background

Christmas Island sits in the Indian Ocean, approximately 2,600km northwest of Perth, Australia (Figure 1). Flying Fish Cove is located on the north-western tip of the island at the toe of a steep volcanic escarpment.

The cove has been subject to frequent rockfall and debris flow events in recent years. Rockfall fences and earthen berms were constructed to protect the community and infrastructure however these were proven inadequate following several debris flow events between 2014 and 2017. Of note, was a significant rainfall event in 2017 that triggered major debris flows and led to the destruction of an existing rockfall fence. The debris flow blocked access to the public car park and to the Island's sewage treatment plant and fuel storage facility. This event highlighted the need to reduce the landslide risk to the public.

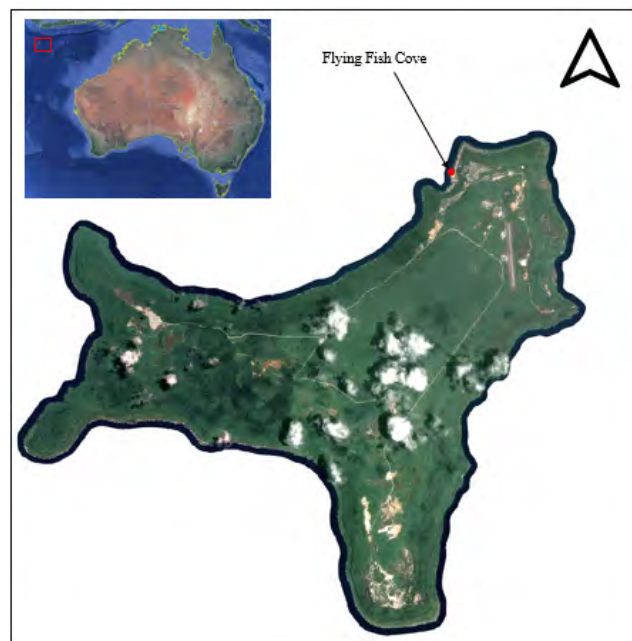


Figure 1 Site Location Map

## 1.2 Previous Studies

Slope instability at Flying Fish Cove has been the subject of numerous geotechnical assessments by multiple parties over the past 30 years.

The most recent and comprehensive assessment of landslide hazards at Flying Fish Cove is a Quantitative Landslide Risk Assessment prepared by GHD in 2018

[1]. The report assessed the risk of debris flow and rockfall hazards at six individual sites (Sites A-F) as illustrated in Figure 2.



Figure 2 - Flying Fish Cove site layout

Three of the sites assessed were identified as exceeding the tolerable limits for risk of loss of life of  $10^{-4}$  for an existing slope and  $10^{-5}$  for an existing landslide as defined by Australian Geomechanics Society [6]. A summary of the hazards identified by GHD at each of the three sites is provided in Table 1.

Table 1 - Summary of hazards that exceed tolerable risk levels (GHD, 2017)

Site	Hazard	Risk of loss of Life
Site A Boat club area / car park	Very large debris flow	$1.39 \times 10^{-4}$
Site A Boat club area / car park	Extremely large debris flow	$1.58 \times 10^{-4}$
Site B Marine Building	Very large debris flow	$1.11 \times 10^{-3}$
Site B Marine Building	Extremely large debris flow	$6.31 \times 10^{-4}$
Site E Madrasa / Shop Area	Very large debris flow	$1.11 \times 10^{-4}$

### 1.3 Scope of Work

Arup has been engaged by DITCRD to undertake 30% (concept) design for landslide mitigation to reduce the risk to acceptable levels for the Site A, Site B, and Site E.

An options assessment carried out by Arup in 2019 [1] assessed a range of criteria, including risk reduction, constructability, design life, environmental and social impact and cost, to conclude that the preferred mitigation option for Sites A, B and E would be a debris flow / rockfall fence (i.e. a flexible barrier).

This report presents the conceptual design for the fence option.

## 1.4 Design Drawings

The design drawings for the proposed mitigation measures are summarised in Table 2.

Table 2 - List of Drawings

Drawing No.	Revision	Drawing Title
CI-DI-0001	Final	Cover Sheet, Index and Locality Plan
CI-DI-0002	Final	General notes and legend
CI-DM-0101	Final	Demolition plan – General arrangement – Sheet 1 of 2
CI-DM-0102	Final	Demolition plan – General arrangement – Sheet 2 of 2
CI-GA-0201	Final	Proposed Works – General arrangement – Sheet 1 of 2
CI-GA-0202	Final	Proposed Works – General arrangement – Sheet 2 of 2

Landslide Mitigation Concept Design

# Site Description

## 2 Site Description

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### 2.1 General

Christmas Island is situated in the Indian Ocean, approximately 2,600km northwest of Perth, Australia. A site location plan is shown in Figure 1. Flying Fish Cove is positioned on the north-western tip of the island and contains key infrastructure for the island community including recreational, commercial, residential and educational facilities. A plan of Flying Fish Cove existing infrastructure is on Drawings CI-DM-0101 and CI-DM-0102. The descriptions provided below have been informed from a variety of sources, including site observations from Arup personnel in May 2019.

### 2.2 Topography and drainage

Flying Fish Cove forms an arcuate bay facing toward the northwest. From the shoreline, the cove topography is defined by a relatively flat and narrow area which varies in width from less than 10m in the west to about 100m in the east. Behind this flat coastal area the ground rises rapidly in a concave hill slope to about 180m above sea level. The upper part of the hill slope comprises very steep slopes generally in excess of 40° with many cliff elements in excess of 70°. The western part of the Cove is particularly steep and is comprised predominantly of cliffs.

The slopes of the cove are densely vegetated; generally with mature trees, as is evidenced by the aerial imagery in Figure 3.

There is very little evidence of any naturally occurring well-developed surface drainage channels. A few poorly developed preferred drainage lines may flow during periods of heavy rain.

Bowden [3] noted that storm water drainage was being discharged from the Drumsite, a development located directly above the Boat Club car park. The position of the Drumsite relative to the Boat Club is indicated in Figure 3. There were also several springs observed at the toe of the cliffs. Since Bowden's 2017 report [3], a new storm water drainage system was installed at the Drumsite, effectively re-directing the storm water away from the slope. The Flying Fish Cove Harbour Master recently noted that the installation of the new storm water drainage has reduced the springs after a heavy rainfall (personnel communication 15 May 2019).



Figure 3 - Drumsite Location

### 2.3 Existing Assets

Flying Fish Cove is lined by numerous buildings used for recreational, commercial, residential and educational activities as indicated in Figure 2. A number of utilities service the island community, including gas, electricity and water. The distribution of utilities across the site is shown on drawings CI-DM-0101 and CI-DM-0102 in Appendix A.

GHD [1] indicated that rockfall barriers were initially installed between 1995 and 1999 in areas deemed to be at greatest risk of rockfall. The barriers were ultimately extended sometime after 2000 to stretch across the full extent of Flying Fish Cove. Earthen berms were also installed between 2000 and 2003 to provide additional protection from rockfall hazards.

The general arrangement of the rockfall fences and earthen berms are illustrated in Figure 4.

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Figure 4 - Existing mitigation measures

## 2.4 Geology

### Regional Geology

Christmas Island forms the tip of a submerged seamount comprised primarily of basaltic volcanic rocks. Tertiary-aged sediments comprising interbedded limestones and volcanics cap the basaltic core of the island and are obscured in part by phosphate-rich superficial deposits.

The geology of Christmas Island was illustrated succinctly by Grimes [7] in a diagrammatic cross-section shown in Figure 5.

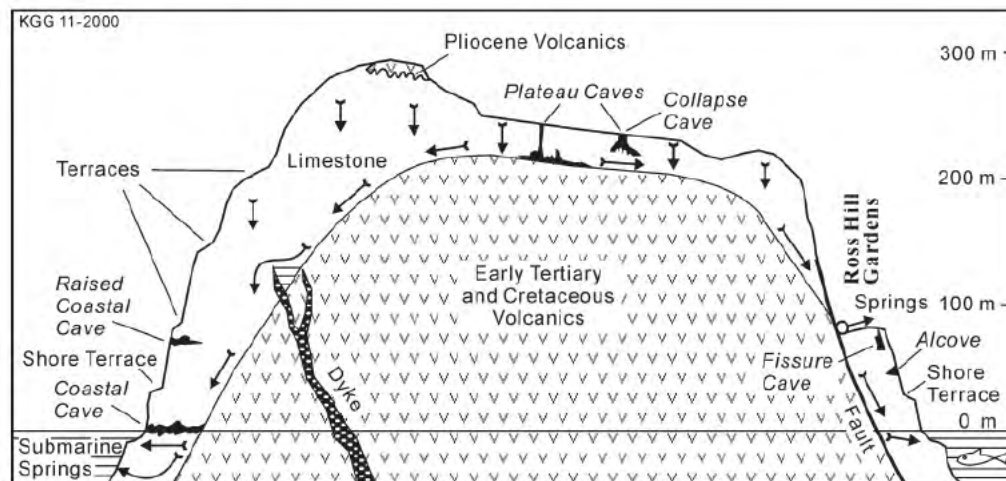


Figure 5 - Diagrammatic cross-section of Christmas Island geology (Grimes, 2001)

## Local Geology

Detailed mapping of Flying Fish Cove geomorphology was carried out by Golder in 1995 and complimented by further mapping by Baynes in 2000 [5].

The mapping indicates that Flying Fish Cove is predominantly underlain by limestone and volcanic dykes. The limestone is noted to generally dip toward the south-east at angles of up to 50° and is extensively faulted; fault trends are generally parallel and dip steeply out of the slope.

Volcanic units, specifically trachyte and basalt, are part of the volcanic core of the Island, and are exposed in cliff bands on the upper slopes above the Cove. At the contacts between the volcanic units and limestone there is evidence of low-grade metamorphism.

The ground surface of the slope is mantled with various superficial deposits (Baynes 2000, [5]):

- Extensive areas of recent rockfall debris (gravel and boulders) derived from the actively degrading cliffs
- Older un-cemented accumulations of rockfall debris on which soil has developed (talus)
- Cemented slope deposits (colluvium)
- Limestone – raised beach deposits (Beach rock)
- Volcanic units – exposed on the upper cliff bands.

## 2.5 Environment

Christmas Island contains a number of environmental and heritage features that need to be considered during design and construction. A detailed assessment of the environmental issues has been undertaken and is presented in Appendix B.

Landslide Mitigation Concept Design

# Design Basis

## 3 Design Basis

### 3.1 Performance Objective

The performance objective is to reduce the risk of loss of life to below tolerable levels for existing landslide slopes ( $10^{-5}$ ). Generally acceptable would be well below the tolerable limit of  $10^{-5}$  per annum as recommended by the AGS [6].

Given that the existing risk of loss of life is considered to  $10^{-3}$  to  $10^{-4}$  across Sites A, B and E, any risk reduction measure would need to reduce risk by approximately two orders of magnitude ( $10^{-2}$ ).

### 3.2 Landslide volumes

The GHD report classified historic landslides based on the volume of material estimated to reach the toe of the slope. This classification is reproduced in Table 3.

Table 3 - Landslide Source Volume Classification (GHD, 2018)

Source Volume (m <sup>3</sup> )	Volume Classification
<0.1	Very Small
0.1 – 1	Small
1 – 10	Medium
10 – 100	Large
100 – 1000	Very Large
>1000	Extremely Large

Some discrepancy was noted in the GHD classification, particularly the use of source volume or toe volume for classification. Furthermore, the 1935 event appears to have been treated as one singular landslide whereas records indicate it was in fact three separate slides [1]. These discrepancies appear to have carried through to the landslide volume frequency modelling.

For clarity, source volumes of the Historic Landslide record have been re-classified based on the volume ranges presented in Table 3. The results of the re-classification are summarised in Table 4.

Table 4 - Summary of historic landslides

Event <sup>1</sup>	Year	Name	Source Volume (m <sup>3</sup> )	Volume at toe (m <sup>3</sup> )	Comment	Volume Classification
1a	1935	-	350	-	Back-calculated	Very Large
1b	1935	-	1100	-	Back-calculated	Very Large
1c	1935	-	439	-	Back-calculated	Very Large
2	2014	Madrassa	132	-	Stopped by 1000kJ fence	Very Large

Event <sup>1</sup>	Year	Name	Source Volume (m <sup>3</sup> )	Volume at toe (m <sup>3</sup> )	Comment	Volume Classification
3a	2016	Basketball Court	1000	-	Stopped by 1000kJ fence	Very Large
3b	2016	Basketball Court	250	-	Stopped by 1000kJ fence	Very Large
4	2016	Boat Club	15	465	Breached 1000kJ fence	Large
5	2016	412	40	-	Stopped by 1000kJ fence	Medium
6	2017	Boat Club	2025	700	Breached 1000kJ fence	Extremely Large

<sup>1</sup>Landslide Event numbering based on GHD (2018)

### 3.3 Probability of Landslide Occurrence

Noting the discrepancy in the GHD reporting of the classification of source volume and volume of material that reached the toe, a revised landslide magnitude frequency has been developed using the summary of historical and recent landslides in Table 4. The revised landslide magnitude frequency assessment is presented in figure 6 and suggests a 2,000m<sup>3</sup>, equivalent to the 2017 Boast Club event, has a recurrence of 0.006 (1/166years). The landslide magnitude frequency assessment is provided in Appendix C1.

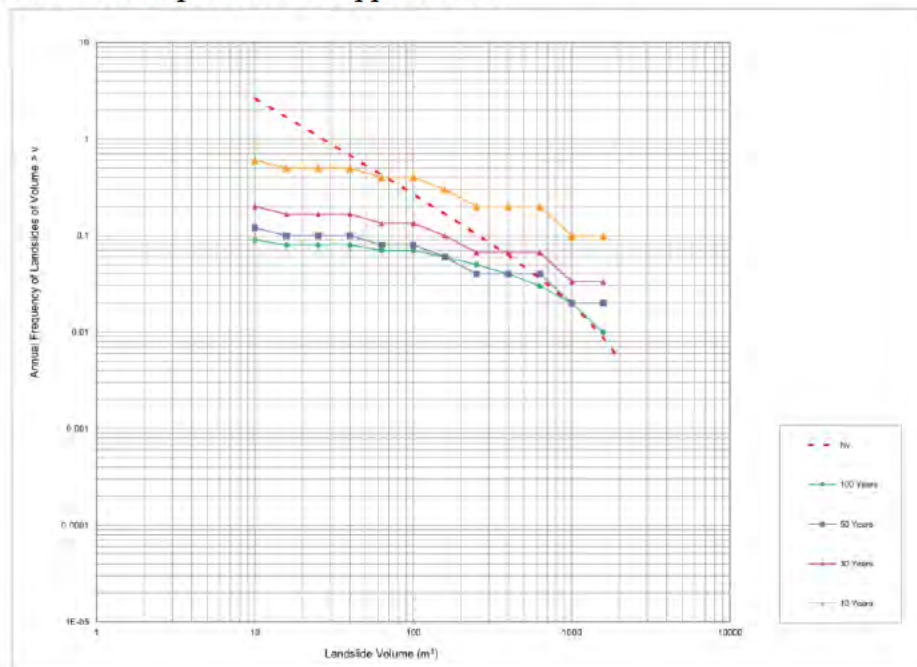


Figure 6 - Landslide Annual Frequency versus Volume (by Year)

### 3.4 Back Analysis

Debris mobility modelling was conducted using DAN/W software to back-analyse the landslides located below the escarpment in the Flying Fish Cove area.

The back-analysis were carried out to obtain the parameters required for the subsequent prediction modelling of landslides in the area within a similar geomorphological setting. Due to the insufficient information available, only three landslides were used for back analysis. These landslides coincide with cross sections 3, 5 and 6 shown in Figure 7.



Figure 7 - Landslide back analysis source volumes and layout plan

### 3.4.1 Data

Key data sets used for debris mobility and rockfall modelling are:

- GHD (2018) Flying Fish Cove, Christmas Island Quantitative Landslide Risk Assessment, Department of Infrastructure, Transport, Cities and Regional Development, and;
- Airborne Laser Scanning, Digital Elevation Model (2018), Department of Infrastructure, Transport, Cities and Regional Development.

### 3.4.2 Input parameters

The main input parameters for the back-analysis include:

- Source volume
- Entrainment thickness (if presented)
- Longitudinal profile
- Channel cross sectional shape
- Width variation along the longitudinal profile.

These parameters were extracted from the GHD report [1] and supplemented with the most current topographic data. Specific input parameters used for the three cross sections are described below and presented in Table 3.1 of Appendix C2.

### **Landslide 3 – Basketball Court Landslide**

- Source volume of 1,250m<sup>3</sup> (assume sheet of material 40 m (L) by 21m (W) by 1.5m (D))
- Source area within talus
- 27m<sup>3</sup> of debris was recorded at the location of the existing rockfall fence, this volume was back-analysed to correlate against the volume of debris passing this point.

### **Landslide 5 – 412 Landslide**

- Source volume of 40m<sup>3</sup> (assume spoon shaped and 10m (L) by 5m (W) by 1.5m (D))
- Source area within talus
- About 25% of the debris (10m<sup>3</sup>) reached the rockfall fence at the slope toe with the rest being deposited on the slope above.

### **Landslide 6 – Boat Club Landslide, 2017**

- Source Volume 2,000m<sup>3</sup> (assume sheet of material 40m (L) by 25m (W) by 2m (D))
- Source area within talus
- Some flow impedance by existing fences but about 700m<sup>3</sup> overtopped these and deposited in car park at toe.

## **3.4.3 Results**

The results of the back analysis are presented in Appendix C2. It was observed that these landslides were open hillslope failures (up to 25m wide) with little to no entrainment. As such, frictional rheology was suggested for the debris mobility analysis for open hillslope failure.

Back analysis of Landslides 3, 5 and 6 (which had largely unimpeded run-out) revealed basal friction angles of 31°, 32° and 26° respectively. Empirical reviews of debris travel distance and travel angle showed the mobility to be quite typical.

## **3.5 Landslide Predictive Modelling**

Debris mobility modelling was carried out using DAN/W software to assess the potential impact the landslide hazards would have on the existing assets at the toe of the natural hillside. The debris mobility assessment was carried out for Sites A, B and E.

Three cross sections have been generated based on the 2018 LiDAR survey DTM, namely Section A, Section B and Section E illustrated in Figure 8. ‘Observation

points' were selected for each cross section to indicate the point at which the proposed debris flow barrier would be installed.



Figure 8 - Landslide Predictive Modelling Sections

### 3.5.1 Parameters for analysis

Parameters adopted for the debris flow modelling are summarised in Appendix C3. All three landslides were modelled to reflect an open hillslope failure. A source volume of 2,000m<sup>3</sup> was adopted to reflect an approximate 1 in 100 year event (refer Section 3.3).

A friction angle of 29.5° has been adopted for the predictive analysis based on back analysis results.

### 3.5.2 Results

Three landslide predictive paths have been modelled at Site A, Site B and Site E. The results of which are presented in Appendix C3 and summarised below.

#### Site A – Boat Club Car Park

A debris mobility model was generated for Section A, indicated in Figure 8. The landslide source was taken from within the talus and an open hillslope failure was assumed.

The predictive analysis model for a source volume of 2,000m<sup>3</sup> suggests that the debris run-out of this failure would pass the observation point and has the potential to reach the boat club car park. A debris velocity of up to 6.3m/s was recorded at the observation point. The modelling results also show that the total

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debris passing through the observation point could be approximately 123m<sup>3</sup>. An estimated energy of 4,629kJ was recorded.

Site observations indicate that the 2017 event was a channelised debris flow however the event modelled above assumes an open hillslope failure. It is noted that if the model were to reflect a channelised flow, the velocities and debris volumes would likely be significantly higher. For reasons described in Section 5.1, the likelihood of a channelised debris flow event is considered to be less likely given recent changes to site drainage.

### **Site B – Marine Building**

A debris mobility model was generated for this catchment as indicated in Figure 8. The landslide source was taken from within the talus and a volume of 2,000 m<sup>3</sup> was adopted. An open hillslope failure was assumed.

The predictive analysis for this model suggests that the debris run-out of this failure will pass the observation point and has the potential to reach the Marine Building. A debris velocity of up to 6.1m/s was recorded at the observation point. The modelling results also show that the total debris passing through the observation point could be up to 130m<sup>3</sup>. An estimated energy of 4,679kJ was recorded.

### **Site E – Madrassa / Shop Area**

A debris mobility model was generated for this catchment as indicated in Figure 8. The landslide source was taken from within the talus and a volume of 2,000 m<sup>3</sup> was adopted. An open hillslope failure was assumed.

The predictive analysis for this model suggests that the debris run-out of this failure will pass the observation point and has the potential to reach the Madrassa / Shop Area. A debris velocity of up to 6.1m/s was recorded at the observation point. The modelling results also show that the total debris passing through the observation point could be up to 195m<sup>3</sup>. An estimated energy of 6,825kJ was recorded.

## **3.6 Rockfall Modelling**

Observations from the Arup site walkover in 2019 indicated blocks at the toe of the slope. The source of the rockfall was assessed to be the steep rock cliff at the top of the escarpment.

Rockfall analysis has been carried out using the RocFall Version 4.0 (RocScience, 2010) software programme.

### **3.6.1 Parameters for analysis**

Parameters adopted for the rockfall analysis are presented in Table 3.1 Appendix C4.

Since the rock fragments along the rock cliffs identified within the hillside would likely be mobilised at the same time in the event of failure, line seeders with a combined volume of 3.5m<sup>3</sup> was employed in the predictive models.

### 3.6.2 Results

The key findings of the rock fall assessment are summarised below and presented in Appendix C4.

- Site A: One predictive model was analysed to simulate rockfalls from the rock cliff. The analysis indicated that the rock fragments could travel across the proposed mitigation measures location at the toe of the hillside and reached the toe facilities. The results suggested that rock fragments have a maximum velocity of 11.8m/s, a maximum kinetic energy of 938kJ and a maximum bounce height of 0.1 m.
- Site B: Two predictive models were analysed to simulate rock falls from the lower rock cliff and higher rock cliff respectively. The analysis indicated that the rock fragments could travel across the proposed mitigation measures location at the toe of the hillside and reached the toe facilities. The worst case (from high cliff) suggested that rock fragments have a maximum velocity of 22.7m/s, a maximum kinetic energy of 2932kJ and a maximum bounce height of 3.6 m.
- Site E: One predictive model was analysed to simulate rock falls from the rock cliff. The analysis indicated that the rock fragments could travel across the proposed mitigation measures location at the toe of the hillside and reached the toe facilities. The results suggested that rock fragments have a maximum velocity of 8.7m/s, a maximum kinetic energy of 527kJ and a maximum bounce height of 0.2 m.

Landslide Mitigation Concept Design

# Mitigation Design and Risk Inputs

## 4 Mitigation Design and Risk Inputs

### 4.1 General

The proposed mitigation design is for appropriately sized debris flow / rockfall fences to be installed at Sites A, B and E and replace the existing fences as per Table 5. The proposed mitigation for Site E comprises the partial replacement of the southern portion of the CI Club Fence and slight extension to overlap Fence 408.

Table 5 - Site Fences

Site	Existing Rockfall Fence	Comment
Site A	Boat Club & Marine Building 2	Complete replacement
Site B	Marine Building 1	Complete replacement
Site E	CI Club	Partial replacement ~60m of southern extent of CI Club + add 10m to overlap with Fence 408

This mitigation measure was selected by DITCRD as the preferred option as a result of the Flying Fish Cove Landslide Mitigation Options Assessment (2019) [1]. The existing rockfall fences would need to be removed to allow installation of the new debris flow / rockfall fences.

Debris flow / rockfall fences require ongoing maintenance and as such require vehicle access allowing for turn-arounds along areas the fence alignment. Whilst access can be easily maintained at Site E, Site A and B remain relatively inaccessible owing to the natural terrain. A new access track is therefore recommended at the western end of Site A.

Typical layouts of the proposed mitigation design and access road are indicated on Drawing CI-GA-0201 and CI-GA-0202.

### 4.2 Design Volume and Energy

Based on our own assessment of historical landslides, site observations and experience at Christmas Island, Arup has adopted a landslide volume of 2,000m<sup>3</sup> from a single source for landslide predictive modelling. This is the 1/100 annual probability of exceedance event.

Landslide predictive modelling for Site A, Site B and Site E confirmed the potential for landslide debris to reach the elements at the toe of the slope.

The proposed design parameters are listed in Table 6 along with the corresponding energy level based on impact velocity and debris volume at each location.

Table 6 - Summary of design hazard data 2,000m<sup>3</sup> source volume

Site	Fence	Hazard Type	Volume of Debris Reaching Proposed Barrier Locations (m <sup>3</sup> )	Design Volume (m <sup>3</sup> )	Calculated Energy Level (kJ)	Design Energy Level (kJ)
A	Boat Club	Open Hillslope Failure	125	130	4629	8600
A	Marine Building 2	Open Hillslope Failure	125	130	4629	5000
B	Marine Building 1	Open Hillslope Failure	1309	130	4679	5000
E	CI Club	Open Hillslope Failure	195	200	6825	8600

The design energy level has been rounded up to be aligned with specifications of available proprietary products.

### 4.3 Proposed height

To better predict the minimum height required for the debris flow / rockfall fences, 3-dimensional analysis using LS-DYNA were performed on the three selected sites. The debris flow / rockfall fences were only modelled as rigid shell elements.

The maximum debris thickness at the barrier locations are extracted and summarised in Table 7.

Table 7 - Summary of proposed fence height

Site	Fence	Design Energy Level (kJ)	Debris Thickness at Fence Locations (m)	Design Fence Height (m)	Length (m)
A	Boat Club	8600	3.5	5.0	50
B	Marine Building 2	5000	3.5	5.0	120
B	Marine Building 1	5000	4.5	5.0	91
E	CI Club	8600	3.5	4.0	67

Landslide Mitigation Concept Design

# Mitigated Landslide Risk Assessment

## 5 Mitigated Landslide Risk Assessment

The GHD landslide risk assessment was reviewed and modified to inform a revised risk assessment considering the proposed design.

### 5.1 Site A Considerations

#### 5.1.1 Probability of Landslide Occurrence

##### **Boat Club Fence**

The 2016 and 2017 debris flows at the Boat Club were described by Bowden [3] as channelised debris flows. It is likely that the channelised nature was in part caused by the increased storm water run-off from the Drumsite development located at the crest of the slope. The Drumsite had been undergoing incremental development since the early 2000s, gradually increasing the volume of storm water run-off on to the slope. It can be surmised that the sudden occurrence of channelised debris flows in this area were in part caused by the gradual increase of storm water flow on to the slope directly above the Boat Club.

Following the 2017 Boat Club landslide, it was recognised that the storm water drainage at the Drumsite was a partial contributor to triggering the landslide. The Drumsite drainage was subsequently upgraded to ensure surface water was re-directed away from the slope. Conversations with the Harbour Master during the Arup site visit at Flying Fish Cove confirmed that several springs once known to flow from the toe of the cliff crest are no longer active following the re-direction of the storm water

Noting that the introduction of surface water to the slope was a likely contributor to the 2016 and 2017 Boat Club landslides, it is plausible that by removing the surface water flow, the likelihood of a channelised debris flow would also be reduced and any future events would adopt an open hillslope flow.

##### **Marine 2 Fence**

The 1935 landslide is the only recorded debris flow event to have occurred at Marine 2 Fence location. Due to the limited quality of information for this event, there is some uncertainty as to its exact position on the slope. There is no record of an extremely large landslide occurring at this fence since records commenced in 1895. As such, the probability that an 'extremely large' event would occur is reduced.

#### 5.1.2 Source

##### **Boat Club Fence**

Bowden [3] recognised that the 2016 and 2017 landslides occurred within the talus material. A significant volume of talus was transported during these events. Whilst it is recognised that a significant volume of talus still remains on the slope,

the sheer magnitude of material transported previously would have somewhat depleted the availability of source material.

## Marine 2 Fence

Limited history of debris flows in the area suggest that there is still ample source material for a debris flow to occur.

### 5.1.3 Temporal Probability

#### Boat Club Fence and Marine 2 Fence

The GHD Report [1] assumed that on a typical day, any person may spend up to 2 hours in the car park, near the retaining wall. The AGS [6] stipulates that the risk assessment should be for the individual most at risk. It is unlikely that a single person would spend 2 hours every day (or 14 hours a week) in the car park.

AGS stipulates that larger populations should be assessed as Societal Risk.

### 5.1.4 Spatial Probability

#### Boat Club Fence and Marine 2 Fence

The Boat Club car park is approximately 150m long. The QRA suggests that a very large debris flow would cover an area of 25m and an extremely large debris flow would cover an area of 50m. Whilst these distances are realistic, it means that the person most at risk would spend approximately 40% of their time in the impact zone of a landslide. Currently the GHD QRA [1] conservatively assumes that there is 100% chance that the individual would be in the impact zone.

### 5.1.5 Vulnerability

#### Boat Club Fence and Marine 2 Fence

The Boat Club car park could be broken in to two areas; near the retaining wall and, more than 10m away from the retaining wall. The vulnerability of an individual standing more than 10m away from the retaining wall could be up to 50% less than someone standing next to the retaining wall. Currently the vulnerability rating for an individual is 1.0. Considering the variation in distance from the retaining wall, a combined vulnerability of 0.75 could be feasible.

### 5.1.6 Mitigated Risk of Loss of Life

The proposed new fences described in Table 7 are designed for a 2,000m<sup>3</sup> event overland flow event which is estimated to coincide with an approximate 1 in 100 year event ( $10^{-2}$ ) and brings the risk of loss of life to below tolerable limits.

The risk of loss of life has been reviewed for Site A based on a 'very large' open hillslope failure and the mitigation measures proposed in Table 6 are estimated to reduce the risk of loss of life to below tolerable limits.

Extreme events such as the 2017 Boat Club landslide with 700m<sup>3</sup> material transported to the toe are not practical to retain and the fence would be overtopped. Given the discussion above, it is clear that a notable amount of conservatism has been incorporated in to the risk assessment of loss of life at Site A and as such, the risk of an extremely large debris flow would be below the tolerable limit of 10<sup>-5</sup>/annum.

## 5.2 Site B

The general configuration and drainage at Site B has been largely unchanged since the GHD QRA [1] was conducted. A review of the QRA indicates that the spatial probability, temporal probability and vulnerability are all relatively unchanged.

### 5.2.1 Probability of Landslide Occurrence

As discussed in Section 1, there is no record of an extremely large landslide occurring at Flying Fish Cove since records commenced in 1895. As such, the probability that an ‘extremely large’ event would occur is reduced.

### 5.2.2 Mitigated Risk of Loss of Life

The risk of loss of life has been reviewed for Site B based on the new mitigation measures proposed in Table 7. These measures are estimated to reduce the likelihood and vulnerability of the elements significantly, ultimately reducing the risk of loss of life to below tolerable limits.

The design would not mitigate against an extremely large debris flow as this is not considered practical given there is no record of an event this size since records began in 1895. The proposed 5000 kJ fence would provide some mitigation should such an event occur and give those at risk some time to egress the site.

## 5.3 Site E

The general configuration and drainage at Site E has been largely unchanged since the GHD QRA [1] was conducted. A review of the QRA indicates that the spatial probability, temporal probability and vulnerability are all relatively unchanged.

### 5.3.1 Probability of Landslide Occurrence

As discussed in Section 1, there is no record of an extremely large landslide occurring at Flying Fish Cove since records commenced in 1895. As such, the probability that an ‘extremely large’ event would occur is reduced.

Site E comprises the Madrassa and Shop, as illustrated in Figure 2. A review of the 2018 Digital Terrain Model and site observations suggest that there is insufficient material directly above the Shop to enable a ‘very large’ or ‘extremely large’ debris flow. The risk of debris flow for Site E is interpreted to be behind the Madrassa.

### 5.3.2 Mitigated Risk of Loss of Life

The risk of loss of life has been reviewed for Site E based on the new mitigation measures proposed in Table 7. These measures are estimated to reduce the likelihood and vulnerability of the elements significantly, ultimately reducing the risk of loss of life to below tolerable limits.

The design would not mitigate against an extremely large debris flow as this is not considered practical given there is no record of an event this size since records began in 1895. The proposed 8600 kJ fence would provide some mitigation should such an event occur and give those at risk some time to egress the site.

The proposed mitigation design is for a partial replacement of the CI Club Fence and 10m extension west to overlap with Fence 408. As discussed above, the risk of landslides developing behind the Shop is considered to be low given the limited availability of source material. There is a gap between the existing CI Club Fence and Fence 408 that could provide a flow path for future debris flows. The proposed mitigation is to bridge this gap with the new fence.

Landslide Mitigation Concept Design

# Other Works

## 6 Other Works

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### 6.1 Drainage Works

The proposed debris flow / rockfall fences are to be constructed within the footprint of the existing fences which does not increase the existing impervious area. As there is no increase in the impervious area, upgrade to the existing drainage network is not required. Sediment and Erosion Control measures must be put in place during construction to protect the existing storm water system.

### 6.2 Access and Ongoing Maintenance

Permanent access to the debris flow / rockfall fences is required to facilitate future maintenance of all proposed mitigation works. A gated permanent ramp is proposed on the western end of the site to allow access with a skid steer and/or ATV for the purpose of monitoring, repairs or removal of debris. 'Turn around' areas along the length of the fence will also be allowed to make plant access and clean out operations easier.

Maintenance of the proposed mitigation works should be carried out in accordance with the supplier guidelines and a detailed asset management plan (incorporating the supplier maintenance plans updated to suite the new flexible barrier make and model) which aligns with the island wide strategic asset management plan should be prepared to assist with funding allocation for ongoing maintenance.

It is recommended that spare fence parts are kept on Christmas Island in case emergency maintenance works are required and that a monitoring and alert system is implemented to prewarn the community of potential landslide events.

Landslide Mitigation Concept Design

# Conclusion and Recommendations

## 7 Conclusion and Recommendations

This 30% (concept) design report provides details on the project background and landslide history of Flying Fish Cove, Christmas Island. Predictive landslide modelling has been carried out for Sites A, B and E, along with rockfall analysis. This modelling has informed the design requirements for a debris flow / rockfall fence system. The recommended design requirements for the fences are summarised in Table 8 and are based on an event of a 2,000m<sup>3</sup> source material.

Table 8 - Recommend design requirements for debris flow / rockfall fence

Site	Fence	Design Energy Level (kJ)	Design Fence Height (m)
A	Boat club	8,600	5.0
A	Marine 2	5000	5.0
B	Marine 1	5000	5.0
E	CI Club	8600	4.0

Extreme events such as the 2017 Boat Club landslide are not practical to mitigate against and will overtop the fence. Nevertheless, the proposed fences will reduce the risk across the site to below tolerable levels.

Further analysis is required at detailed design of critical sections to ensure the flexible barrier structure is specified appropriately. Structural design of the flexible barrier is also required to confirm specifications such as height, width, post spacing and position, and calculated energy loading acting on the flexible barrier.

A formal risk assessment is recommended at detailed design stage to ensure the debris flow and rockfall risk is reduced to within tolerable limits.

A monitoring and alarm system should be implemented to alert residents of any breaches of the debris flow / rock fall fences.

It is recommended that storm water drainage is monitored at the crest and toe of the slope. Any changes to drainage systems such as long-term scouring should be noted and incorporated in to detailed design calculations.

Skid steer and/or ATV access behind the flexible barriers for the purpose of monitoring, repairs or removal of debris will be allowed for by the addition of 'turn around' areas along the length of the fence, and a permanent gated access ramp is proposed at the western end of the site.

A detailed asset management plan which aligns with the island wide strategic asset management plan should be prepared to assist with funding allocation for ongoing maintenance.

Christmas Island is home to a unique crab population that live on the hill slopes. A Crab Management Plan should be developed at detailed design stage to ensure crab migration does not impact the structural integrity of the debris flow / rockfall barriers.

## 8 References

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- [1] GHD (2018) *Flying Fish Cove, Christmas Island Quantitative Landslide Risk Assessment*, Department of Infrastructure & Regional Development and Cities
- [2] Arup (2019) *Flying Fish Cove, Christmas Island Landslide Mitigation Options Report*, Department of Infrastructure & Regional Development and Cities
- [3] Bowden Geological (2017) *Post-landslide Inspection 2017 – Flying Fish Cove, Christmas Island*, Department of Infrastructure and Regional Development
- [4] Golder Associates (1995) *Landslide risk assessment Flying Fish Cove, Christmas Island*
- [5] Baynes Geologic (2000) *Re-assessment of Landslide Risks Flying Fish Cove Christmas Island*
- [6] AGS (2007). Practice Note Guidelines for Landslide Risk Management Australian Geomechanics Society. Australian Geomechanics, Vol 42, No 1.
- [7] Grimes, K.G. (2001), *Karst Features of Christmas Island (Indian Ocean)*. Helicite 37(2), pp41-58

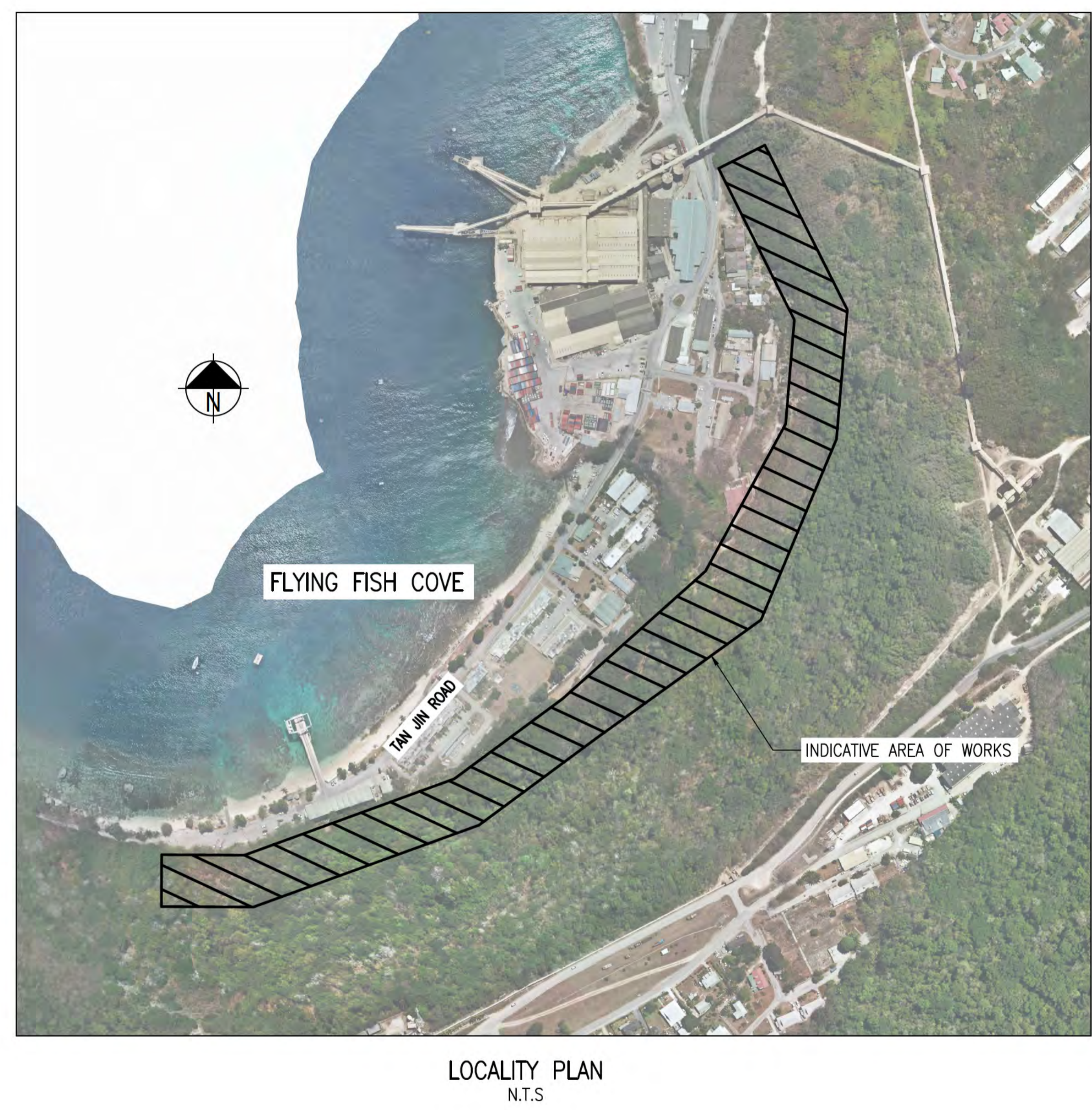
Landslide Mitigation Concept Design

# Appendices

# Appendix A

## Drawings




# FLYING FISH COVE LANDSLIDE MITIGATION 30% CONCEPT DESIGN



**DRAWING INDEX**

DRAWING No	DRAWING TITLE
CI-DI-0001	COVER SHEET, INDEX AND LOCALITY PLAN
CI-DI-0002	GENERAL NOTES AND LEGEND
CI-DM-0101	DEMOLITION PLAN - GENERAL ARRANGEMENT - SHEET 1 OF 2
CI-DM-0102	DEMOLITION PLAN - GENERAL ARRANGEMENT - SHEET 2 OF 2
CI-GA-0201	PROPOSED WORKS - GENERAL ARRANGEMENT - SHEET 1 OF 2
CI-GA-0202	PROPOSED WORKS - GENERAL ARRANGEMENT - SHEET 2 OF 2

**NOT FOR CONSTRUCTION**

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### GENERAL NOTES

1. LiDAR Digital Elevation Model (DEM) survey No 18AU043, dated 20/12/2018 by Diodrone and various GIS files supplied by DITCRD 17/05/2019
2. Limit of works to join in smoothly with existing (where applicable) unless noted otherwise.
3. Drawings must be read in colour print.
4. Dimension shall not be scaled from drawings.
5. These notes are to be read in conjunction with the drawings, general legend and referenced drawings.
6. Design heights shown are finished surface levels.

### EXISTING FEATURES

1. The locations of existing services shown on the drawings have been determined from the known positions of valves, manholes etc. and information supplied by the survey and Department of Infrastructure, Transport, Cities and Regional Development (DITCRD) GIS as provided on 18 May 2019. The services shown on the drawings are provided for information purposes only and no responsibility is taken for the accuracy or completeness of the information supplied. The contractor shall confirm the location, level and sufficient cover to all utilities on site prior to construction of any works, and shall inform the designer of any discrepancies.
2. The contractor is to ensure all existing utility services remain operational at all times. No work is to be carried out on or near existing services without prior notification to the Administrator and obtaining their approval to proceed.
3. Contractor must obtain and complete all utility approvals in accordance with utility provider requirements.
4. Prior to any work commencing that has the potential to impact on existing services, consultation with asset owners must be undertaken to determine their clearance and protection requirements.
5. Contractor to physically locate and confirm and protection works for exiting utility works prior to construction.

### DRAINAGE NOTES

1. Additional due care is required when operating plant in the area of drainage structures. The contractor is to consider construction loadings on the new & existing drainage structures. Any damage caused to new & existing structures, must be repaired or replaced as directed by the Administrator and at cost to the contractor.


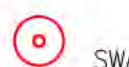
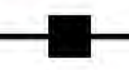


### SLOPE REMEDIATION SOLUTIONS – GENERAL

1. Products shall be installed in accordance with manufactures specifications.
2. The contractor shall submit all necessary certificates of materials and all other information necessary prior to the start of the works in accordance with contract requirement.






























### SLOPE REMEDIATION SOLUTIONS – GROUND CONDITIONS



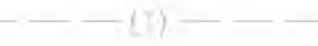


1. The anticipated ground conditions are based on visual inspection of slopes. The contractor shall review all relevant geotechnical investigation data to familiarise themselves with site conditions.
2. The contractor shall satisfy themselves that the methods of working and drilling are suitable for the ground conditions on site. If during the installation of the anchors the ground conditions prove different than what would be anticipated from the ground investigation information, the contractor shall immediately notify the Administrator and Designer.
3. Once the slope is clear of existing fences, vegetation, debris and loose blocks, the slope is to be inspected for signs of instability. Further works will not continue until the inspection is completed and the Administrator confirms works are safe to continue.






### LEGEND

- EXISTING STAY WIRE ANCHOR  SWA
- EXISTING STAY WIRE ANCHOR TO REMOVED  SWA
- EXISTING ROCKFALL FENCE /BARRIER & COLUMN (NTS) 
- EXISTING TO BE REMOVED 
- PROPOSED FELXIBLE BARRIER 

### EXISTING SERVICES LEGEND

- POWER**
  - CONSUMER POLE  CP
  - POWER POLE  PP
  - LIGHT POLE  LP
  - STAY POLE  SP
  - BOARD  PB
  - UNI PILLAR  UP
  - EXPOSED CABLES  EC
- GAS**
  - PRE-LAID CONN.  GPL
  - METER  GM
- SEWERAGE**
  - MANHOLE  SMH
  - INSPECT. SHAFT  IS
  - INSPECT. OPENING  IO
  - HOUSE CONNECTION  HC
  - HOUSE CONN. INDICATOR  HCI
  - INSPECT. SHAFT CONNECTION  ISC
- TELECOMMUNICATIONS**
  - PIT  TEL
  - PRE-LAID CONN.  TPL
- DRAINAGE**
  - MANHOLE  DMH
  - GULLY PIT 
  - LOT PIT  LDP
  - HOUSE CONN.  DHC
  - SIDE ENTRY PIT 
  - COMBINATION ENTRY PIT 
- WATER**
  - STOP VALVE  WSV
  - HYDRANT  HY
  - FLUSH POINT  FP
  - WATER TAP  WTP
  - WATER METER  M
  - PRE-LAID CONN.  WPL

- EXISTING DRAINAGE 
- EXISTING ELECTRICITY 
- EXISTING TELECOMMS 
- EXISTING SEWER MAIN 
- EXISTING WATER MAIN 

- SURVEY**
- TREES 
- HATCHING**
- ROAD SURFACE 
- VEGETATED SLOPE 
- FEATURES**
- BOTTOM OF BANK 
- RETAINING WALL 

**NOT FOR CONSTRUCTION**

Scales

**N.T.S**


Design Model Version





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Department of Infrastructure, Transport, Cities and Regional Development

Client  
**AUSTRALIAN GOVERNMENT  
DEPT OF INFRASTRUCTURE,  
TRANSPORT AND REGIONAL  
DEVELOPMENT**

Engineering Certification (CEng)  
Name: \_\_\_\_\_ Date: \_\_\_\_\_  
Signature: \_\_\_\_\_

Job Title  
**FLYING FISH COVE  
CHRISTMAS ISLAND  
LANDSLIDE MITIGATION  
30% CONCEPT DESIGN**

Scale at A1  
Discipline: **Drawing Discipline**



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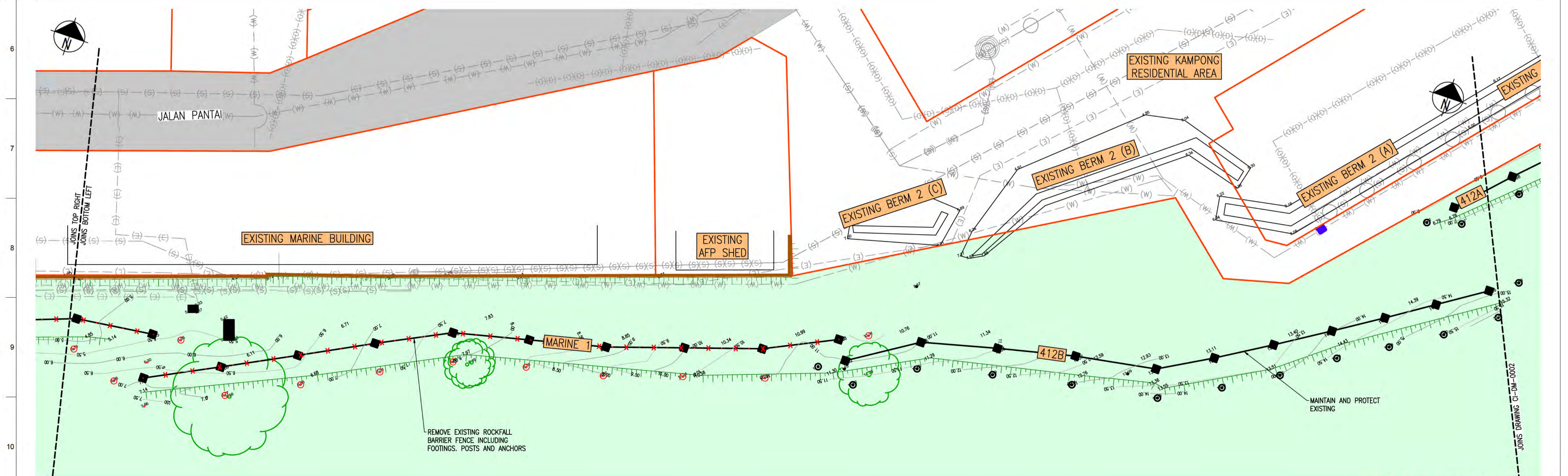
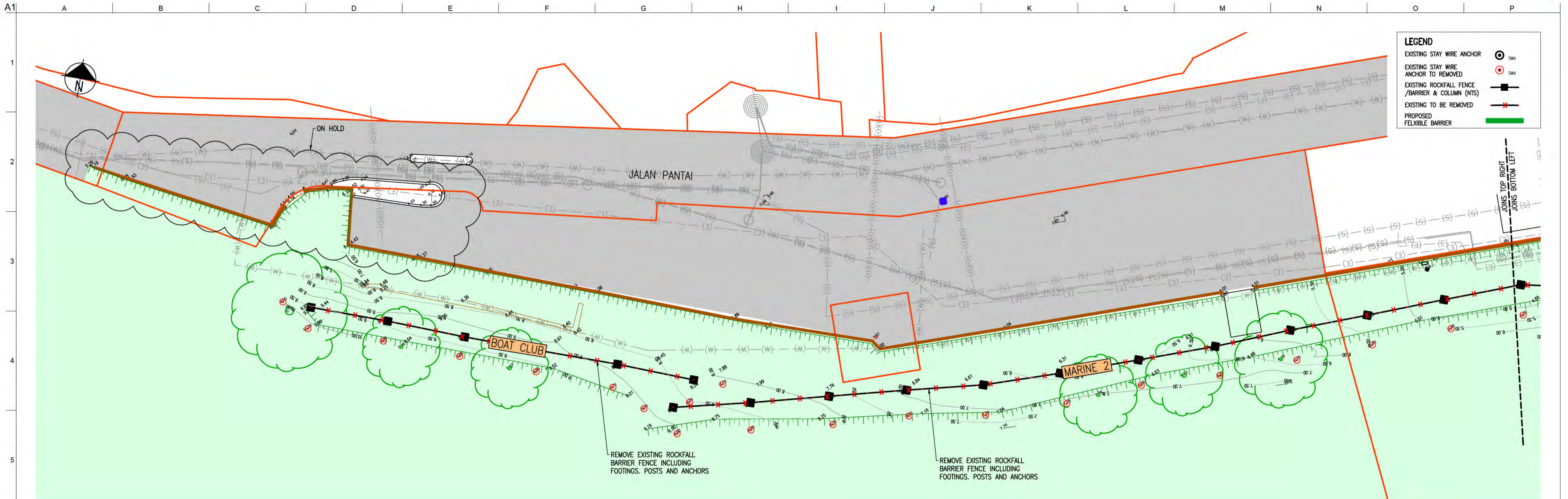
Member Firm  
Arup Pty Ltd  
ABN 16 000 965 165

Drawing Title  
**LANDSLIDE MITIGATION  
GENERAL NOTES AND LEGEND**

Drawing Status  
**Preliminary**

Job No	Drawing No	Issue
<b>268575</b>	<b>CI-DI-0002</b>	<b>02</b>

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Scales

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FINAL ISSUE				
01	26/06/19	LC	MW	
DRAFT ISSUE				

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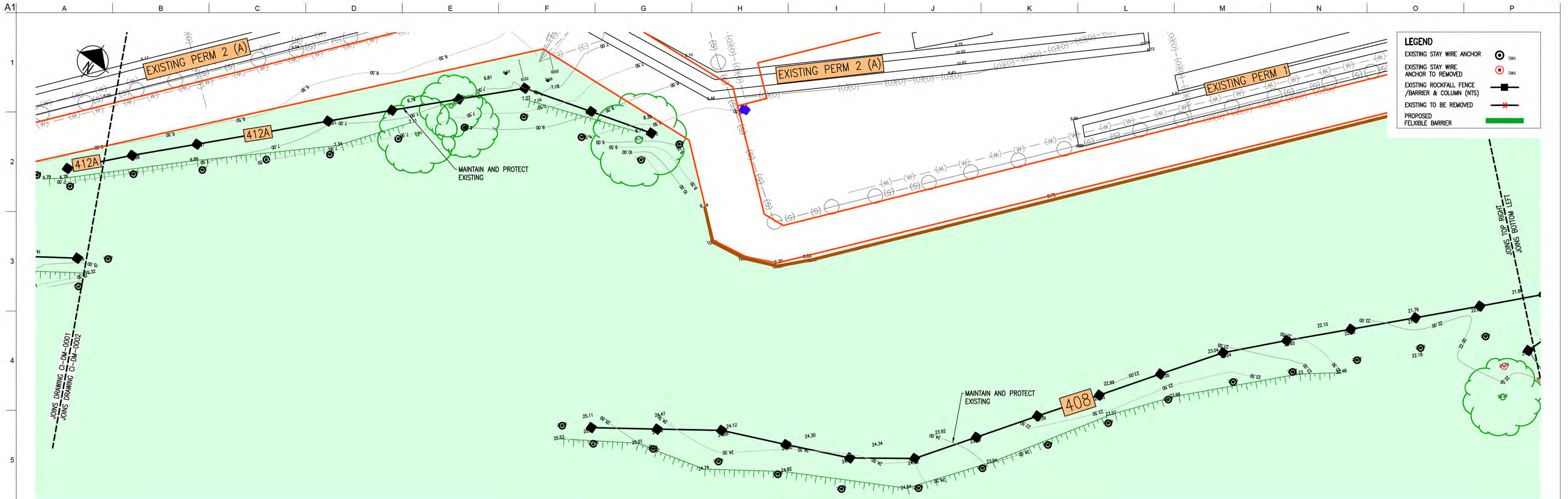
CONSULT AUSTRALIA  
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ABN 18 000 966 165

Drawing Title  
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DEMOLITION PLAN  
GENERAL ARRANGEMENT

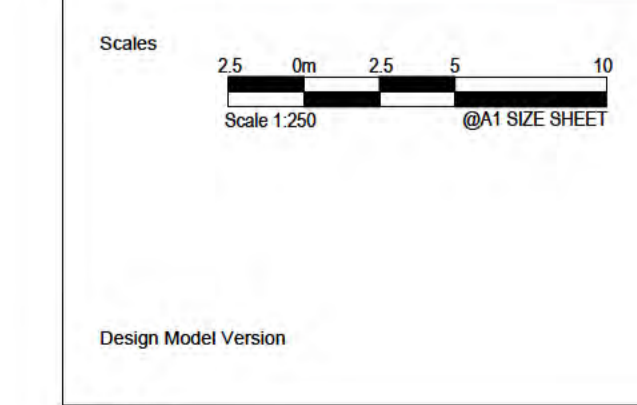
Drawing Status  
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Job No <b>268575</b>	Drawing No <b>CI-DM-0101</b>	Issue <b>02</b>
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FINAL ISSUE				
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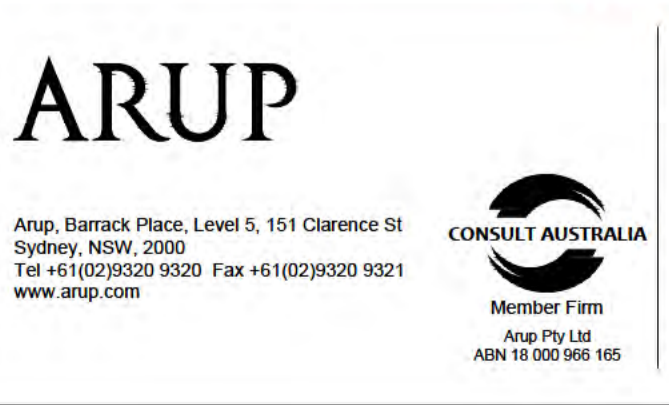


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Job Title  
FLYING FISH COVE  
CHRISTMAS ISLAND  
LANDSLIDE MITIGATION  
30% CONCEPT DESIGN

Scale at A1  
Discipline Drawing Discipline

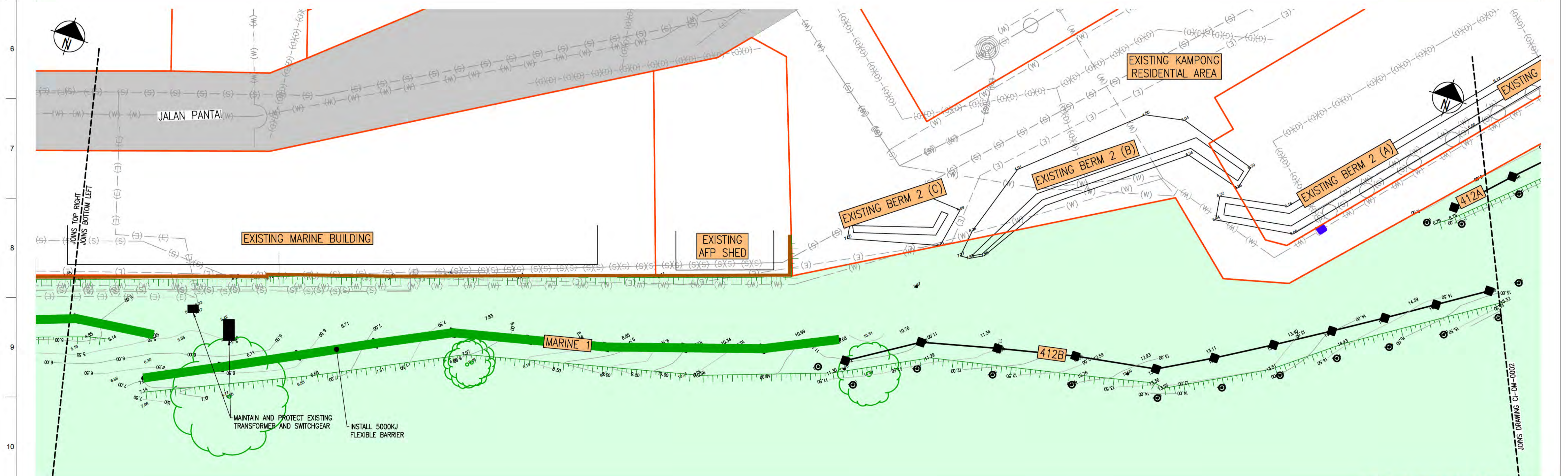
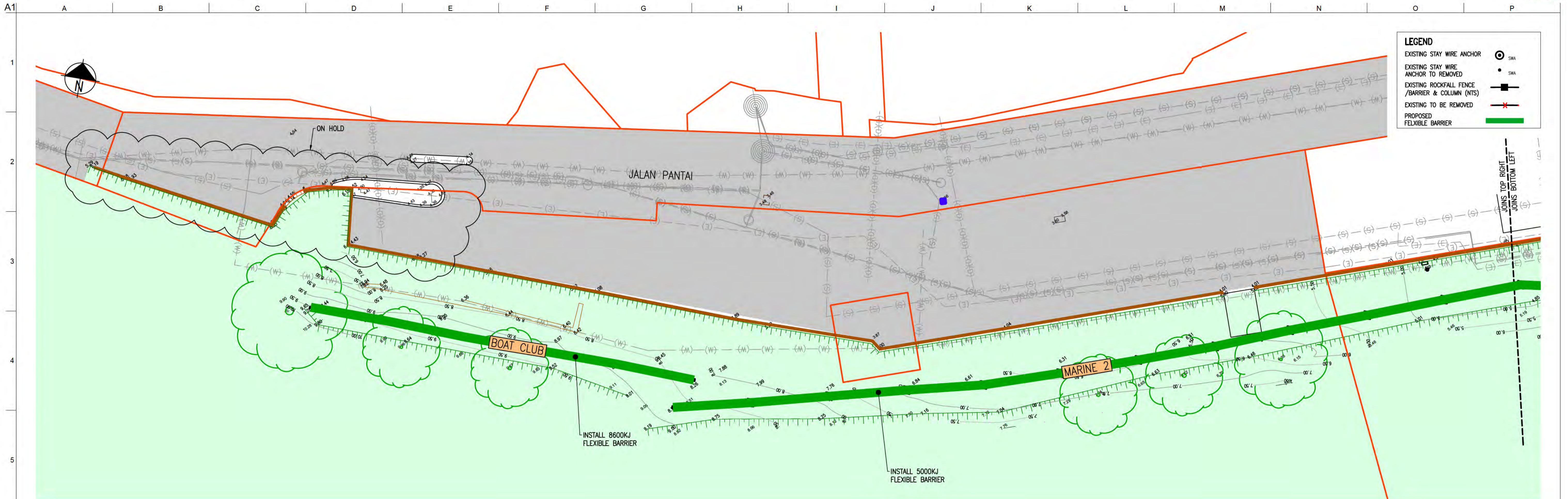


Drawing Title  
LANDSLIDE MITIGATION  
DEMOLITION PLAN  
GENERAL ARRANGEMENT

Drawing Status  
**Preliminary**

Job No	Drawing No	Issue
268575	CI-DM-0101	02

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Scales  
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 Scale 1:250 @A1 SIZE SHEET

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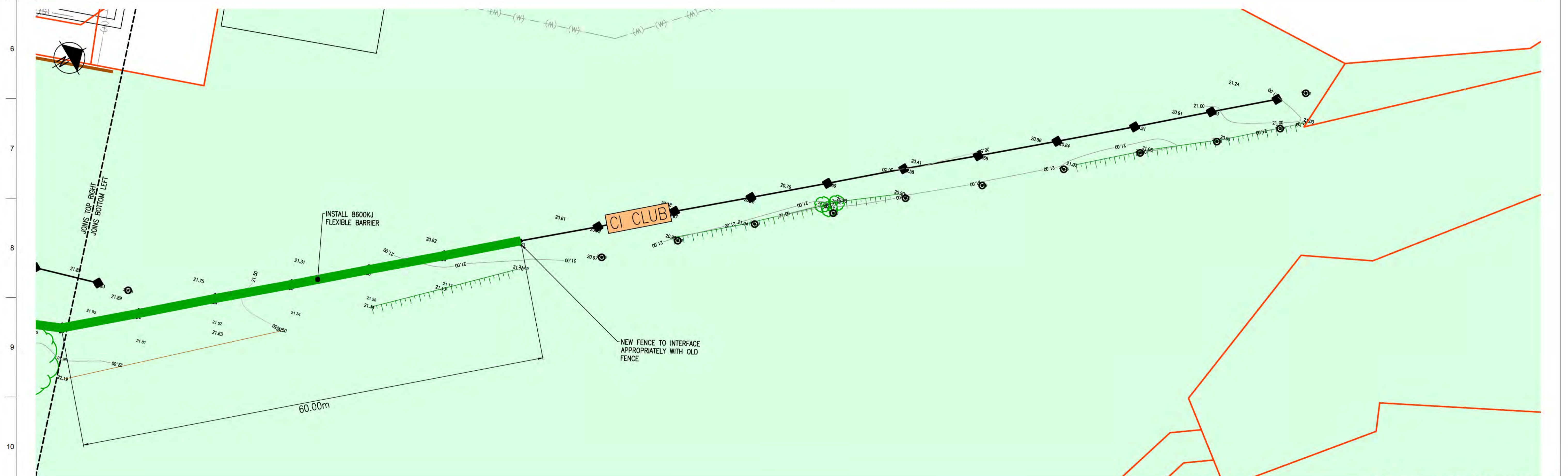
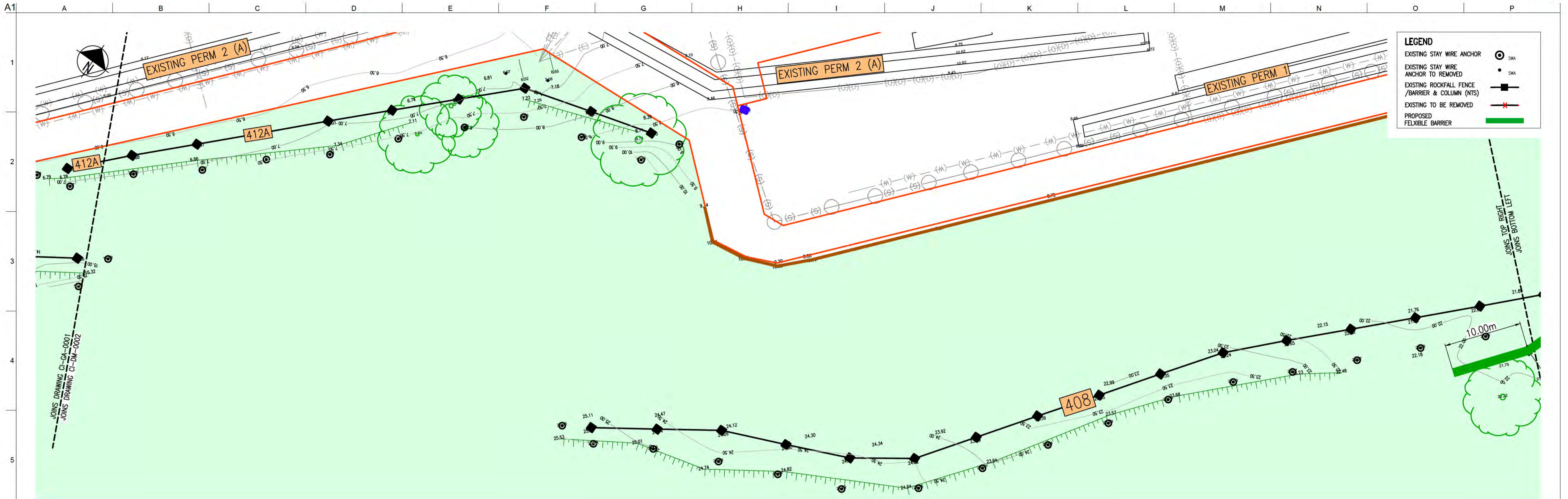
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 ABN 18 000 966 165

Drawing Title  
 LANDSLIDE MITIGATION  
 PROPOSED WORKS  
 GENERAL ARRANGEMENT

Drawing Status  
**Preliminary**

Job No <b>268575</b>	Drawing No <b>CI-GA-0201</b>	Issue <b>02</b>
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01	26/06/19	LC	MW	
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 CHRISTMAS ISLAND  
 LANDSLIDE MITIGATION  
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Drawing Title  
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 PROPOSED WORKS  
 GENERAL ARRANGEMENT

Drawing Status  
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Job No	Drawing No	Issue
268575	CI-GA-0202	02

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## Appendix B

### Environmental Report

Department of Infrastructure,  
Transport, Cities & Regional  
Development

**Flying Fish Cove, Christmas  
Island Landslide Mitigation**

Environmental and Heritage  
Approvals Scoping Report

Final Issue | 15 July 2019

This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Job number 268575

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# Document verification



<b>Job title</b>		Flying Fish Cove, Christmas Island Landslide Mitigation		<b>Job number</b>		268575	
<b>Document title</b>		Environmental and Heritage Approvals Scoping Report		<b>File reference</b>			
<b>Document ref</b>							
<b>Revision</b>	<b>Date</b>	<b>Filename</b>	268575-ENV-REP-001.docx				
Draft 1	26 Jun 2019	<b>Description</b>	First draft for DITCRD review				
			Prepared by	Checked by	Approved by		
		Name	Matt Davis	Effie Fox	Daniyal Mian		
		Signature					
Final	15 July 2019	<b>Filename</b>	268575-ENV-REP-001_Issue.docx				
		<b>Description</b>	Final issue.				
			Prepared by	Checked by	Approved by		
		Name	Matt Davis	Effie Fox	Matt Davis		
		Signature					
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# 1 Background and scope

---

Arup has been engaged by the Department of Infrastructure, Transport, Cities and Regional Development (DITCRD) to design conceptual landslide mitigation to reduce the risk to acceptable levels for specific sites at Flying Fish Cove, Christmas Island. The purpose of this Environment and Heritage Approvals Scoping Report (EHASR) is to:

- Provide a desktop and site review of the environmental constraints at the sites which may impact the repair, replacement and upgrade works;
- Identify any approvals and additional assessments required likely to be required, and;
- Provide a review of the environmental and heritage impacts of the concept design, with recommended mitigation measures to be considered in future project phases.

This report does not provide a legal opinion of the applicability of specific legislation and the triggering of associated approvals. The recommendations are based on Arup's interpretation of available materials, legislation and information provided.

## 2 Project description

---

Christmas Island sits in the Indian Ocean, approximately 2,600km northwest of Perth, Australia. Flying Fish Cove sits is located on the north-western tip of the island at the toe of a steep volcanic escarpment. The cove has been subject to frequent rockfall debris flow events. Rockfall fences and earthen berms were constructed to protect the community and infrastructure however these were proven inadequate following several debris flow events between 2014 and 2017 (**Figure 1**). Of note, was a significant rainfall event in 2017 that triggered major debris flows and led to the destruction of an existing rockfall fence and impact to a public car park. This event highlighted the need to reduce the landslide risk to the public.

Previous studies identified an unacceptable level of landslide risk, requiring addition mitigation to reduce the risk to acceptable levels for the following sites:

- Site A: Boat club carpark;
- Site B: Marine building, and;
- Site E: Madrasa School.

An options assessment carried out by Arup in 2019 assessed a range of criteria, including risk reduction and cost, to conclude that the preferred mitigation option for Sites A, B and E would be a flexible barrier

The proposed mitigation design is for new flexible barriers to be installed at Sites A, B and E. This mitigation measure was selected as the preferred option by Arup in the Flying Fish Cove Landslide Mitigation Options Assessment (2019. The existing rockfall fences would need to be removed to allow installation of the new flexible barriers, with the new barriers occupying a similar footprint as the current rockfall fences).

Flexible barriers require ongoing maintenance and as such require vehicle access. Whilst access can be maintained by the current conditions at Site E, Site A and B remain relatively inaccessible owing to the natural terrain. A new access track is therefore recommended at the western end of Site A.

573200

573400





573600

8847200

8847000



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

-  Flying Fish Cove
-  Site Areas
- Existing mitigation structures**
-  Rock Fall Berm
-  Rock Fall Fence

P1	27-05-2019	MM	TM	EF
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Client  
**Department of Infrastructure, Transport, Cities and Regional Development**

Job Title  
**Flying Fish Cove, Christmas Island**

Drawing Title  
**Site location**

Scale at A3  
**1:1,515**

Job No <b>268106</b>	Drawing Status <b>For Issue</b>
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Figure <b>001</b>	Issue <b>P1</b>
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### 3 Methodology

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The information used in preparing this report included the following activities:

- Searches of a number of relevant mapping, databases and registers maintained by various government agencies to identify any specific details which may trigger the need for a statutory approval, a technical assessment to support an application for such approval or a requirement to be considered in developing the concept design for the proposed works;
- Desktop review of previous reports completed for the site;
- Desktop review of publicly available information of existing development approvals for the site;
- Desktop review of relevant State, regional and local government legislation to identify necessary approvals for the proposed works, and;
- Site visit and walkover by an Arup ecologist on

Desktop sources and searches were used to inform this report, including databases and online search tools to identify anticipated existing conditions, these include:

- *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) Protected Matters Search Tool (PMST) database search, accessed 10 May 2019;
- Christmas Island Vegetation and Clearing Dataset (Geoscience Australia, 2014);
- Atlas of Living Australia database, accessed 10 May 2019, and;
- Australia Heritage Database

## 4 Environmental and heritage conditions

---

### 4.1 Topography

Flying Fish Cove forms an arcuate bay facing toward the northwest. From the shoreline, the cove topography is defined by a relatively flat and narrow area which varies in width from less than 10m in the west to about 100m in the east. Behind this flat coastal area the ground rises rapidly in a concave hill slope to about 180m above sea level. The upper part of the hill slope comprises very steep slopes generally in excess of 40° with many cliff elements in excess of 70°. The western part of the Cove is particularly steep and is comprised predominantly of cliffs.

### 4.2 Water and marine

There is very little evidence of any well-developed surface drainage channels. A few poorly developed preferred drainage lines may flow during periods of heavy rain. Due to the steepness of the terrain there are no defined waterways that traverse the project area. During periods of intense rainfall there will be concentrated runoff in certain areas along the slope.

The adjacent marine environment of Flying Fish Cove includes a shallow fringing reef that provides high level of diversity for marine species. There is a small area of narrow, sandy beach adjacent to the foreshore infrastructure, however nesting resourcing for turtles are very limited due to the constructed, hard edges on the rock walls.

### 4.3 Biodiversity

#### Protected area

The Christmas Island National Park covers the majority of the island, however it excludes areas where mining, industrial and residential land uses dominate. The national park is Commonwealth Reserve, and the boundary of this park is not located within the project area for the fence replacement works.

#### Vegetation and flora

The vegetation communities within the project area consist predominantly of regrowth native vegetation, weed dominated edges and landscaped and informal agricultural areas (**Figure 2**). The vegetation structure is highly influenced by previous clearing in the area, and impacts associated with edge effects and weed incursion. The vegetation is also actively managed by slashing and clearing within the footprint of the current rock fall fences as part of required management.

Further up the slope, more intact native vegetation communities are present. The vegetation on the lower escarpment, adjacent to the project area consists mostly of semi-deciduous forest and scrub. This is consistent with the shallow soils on the steeper escarpments on Christmas Island.

The majority of the vegetation that will be impacted by the installation of the new flexible barriers is regrowth or weed dominated communities. There are some areas within the footprint of the works for Site A (including the access track) and Site E, where there are patches of semi-deciduous forest and scrub. Further upslope the vegetation community becomes more intact and dominated by native species.

### **Fauna and habitats**

Within the likely project area footprint, habitat values for threatened fauna are considered low due to the levels of disturbance from edge effects and weeds.

During field surveys, the following threatened bird species, listed under the EPBC Act were directly observed or heard through calls:

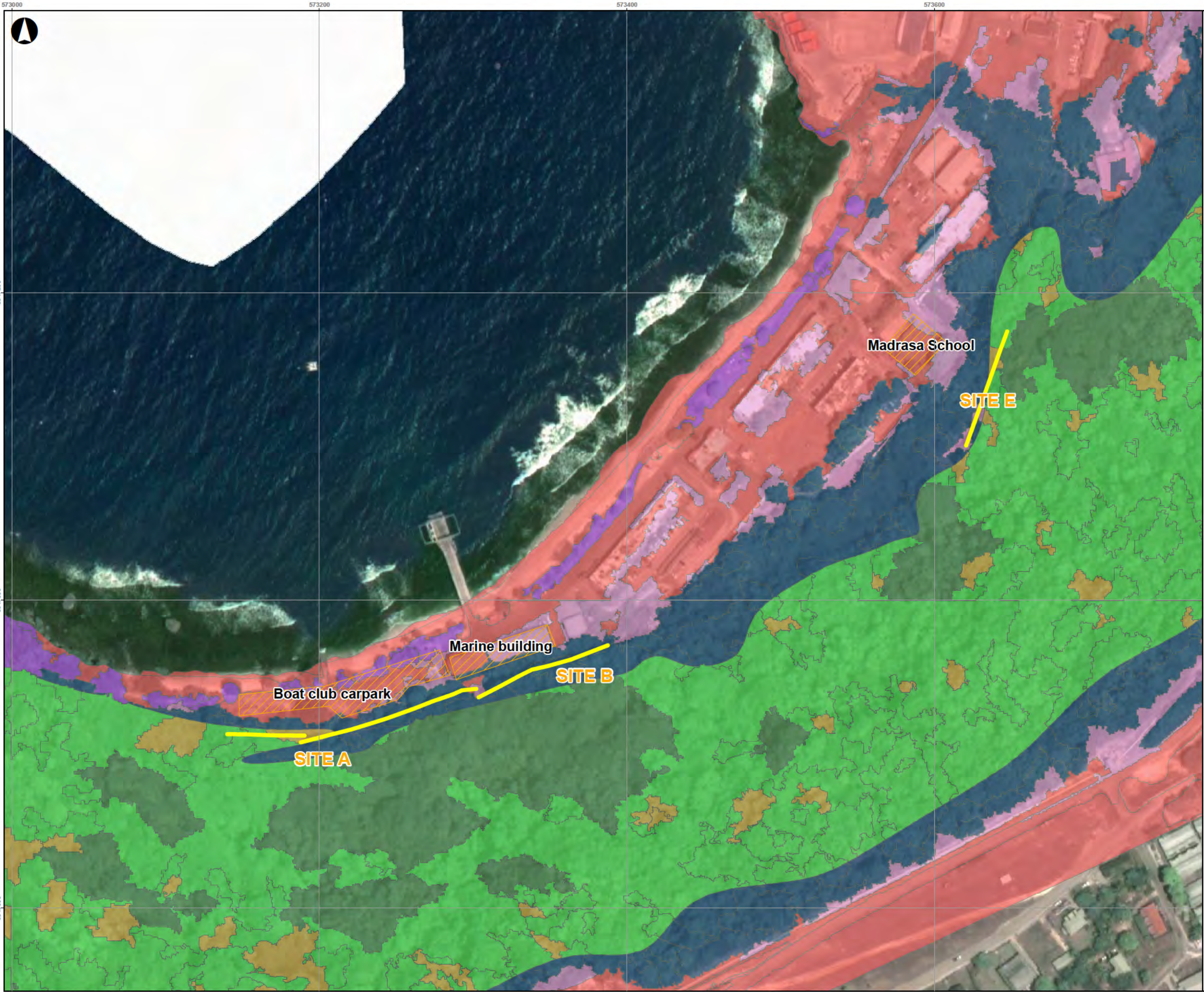
- Christmas Island Thrush *Turdus poliocephalus erythropleurus*
- Christmas Island Hawk-owl *Ninox natalis*
- Christmas Island Emerald Dove *Chalcophaps indica natalis*

As well as the species that were directly observed, there is also suitable habitat for a wide range of common and threatened species within and adjacent to the project footprint.

No threatened flora species were observed during the site visit and the habitat for the potential EPBC Act listed flora species is limited. Threatened flora on Christmas Island are more likely to be found in areas of primary rainforest.

Further up the slope and escarpment, outside of the project area there is a colony of Red-footed Booby, however these will not be directly impacted by the proposed options.

During migration season for the Red Crabs *Gecarcoidea natalis*, it is likely that the species will move down the escarpment to reach the cove. The proposed upgraded flexible barriers are unlikely to cause a permanent barrier for Red Crab migration, as they can move through, over and around the fences. During detailed design it is recommended that opportunities to improve the permeability of the fences for Red Crabs is considered, provided these measures do not compromise the function of the fences at mitigating landslide and rock fall risk.



**Site Areas**

Proposed flexible fence barrier

**Vegetation communities**

- Closed canopy evergreen forest
- Coastal fringe vegetation
- Not vegetated
- Regrowth
- Semi-deciduous forest
- Semi-deciduous scrub
- Weed dominated vegetation & pioneer regrowth

P1	27-05-2019	MM	TM	EF
Issue	Date	By	Chkd	Appd

Metres

0 30 60 120

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Client  
**Department of Infrastructure, Transport, Cities and Regional Development**

Job Title  
**Flying Fish Cove, Christmas Island**

Drawing Title  
**Vegetation communities**

Scale at A3  
**1:2,335**

Job No <b>268106</b>	Drawing Status <b>For Issue</b>
Figure <b>002</b>	Issue <b>P1</b>

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## 4.4 Cultural heritage

There are several sites listed on the Australian Heritage Register on the Commonwealth Heritage List adjacent to the study area (**Table 1** and **Figure 3**). Commonwealth heritage sites are protected as matters of national environmental significance under the EPBC Act. Any actions that are likely to result in a significant impact to a Commonwealth Heritage Site will require referral to Commonwealth Department of the Environment and Energy (DoEE) and if the impacts are significant an approval will be required.

Table 1: Commonwealth Heritage Sites

Site	Description
Christmas Island Natural Areas	<p>Listed specific natural areas of the island for its evolutionary significance, demonstrated by its high level of endemism and the unique plant and animal species. The fringing reefs also supports a rich diversity of marine life. A number of threatened marine and terrestrial fauna also occur on the island.</p> <p>There are no areas mapped within the boundaries of the Christmas Island Natural Areas heritage site associated with the replacement of the flexible barriers. The closest boundary to the works, is on the fence adjacent to Site E, where the heritage site is within 25m of the fence location.</p>
Malay Kampong Group	<p>The places that make up the Malay Kampong area are of special significance to the Malay community of Christmas Island and reflect the ways of life of a cultural minority in Australia (Criterion G.1). The Kampong Area represents one of the main cultural groups on Christmas Island and their endeavours to maintain their religious laws and traditions in a remote setting.</p> <p>The proposed upgrade to the fences will provide additional protection to the Madrasa School (Site E), contributing to the maintenance of the heritage values of this area. This is a recorded Malay cemetery located 8m upslope from the proposed replacement fence at the Marine Building (Site B). This location has been sourced from the Australian heritage register and should be confirmed on site. Additional survey and investigations should be carried out prior to construction to map the on-ground extent of this site.</p>
Industrial and Administrative Group	<p>This area has been the focus of industrial and administrative activity on the island since its earliest occupation and includes evidence of each successive phase of settlement and mining on the island. Some of the oldest structures are located in this area as well as rare evidence of World War ii strafing and the subsequent Japanese occupation.</p> <p>There are no areas in this heritage group directly within the footprint of the works for the fence replacement works. The closest areas are the European cemetery, located approximately 80m upslope and the Christmas Island Club</p>

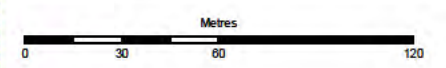
The existing rock fall fences, as well as the proposed mitigation solutions, will contribute to the protection of a number of the heritage sites which occur at the base of the escarpment.



- Commonwealth historical heritage sites**
- Industrial and Administrative Group
  - Malay Kampong Group
  - Site Areas
- Proposed mitigation structures**
- Fence
  - Christmas Island natural heritage site

P1	27-05-2019	MM	TM	EF
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Issue	Date	By	Chkd	Appd



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**Department of Infrastructure, Transport, Cities and Regional Development**

Job Title  
**Flying Fish Cove, Christmas Island**

Drawing Title  
**Commonwealth heritage register**

Scale at A3  
**1:2,335**

Job No <b>268106</b>	Drawing Status <b>For Issue</b>
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Figure <b>003</b>	Issue <b>P1</b>
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## 5 Legislative framework

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### 5.1 Statutory context

Christmas Island is a territory of the Commonwealth Government, with some elements of Western Australian environmental and heritage legislation being applicable Commonwealth legislation considered in this assessment includes the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), which provides for the regulation of the environmental impacts of actions on matters of national environmental significance (MNES).

The Island is governed by Commonwealth law and administered by the DITCRD. However, under the *Applied Laws (Implementation) Ordinance 1992* laws passed by the Western Australian parliament are applied on Christmas Island, along with the body of Commonwealth law that applies elsewhere in Australia. Applied Western Australian laws are administered by the relevant Commonwealth Minister, by Commonwealth officers acting under ministerial delegations or by State officers exercising delegated power and acting pursuant to intergovernmental agreements.

A review of these approvals, permits, self-assessment and compliance are outlined in **Table 2**.

Table 2: Legislative context and applicability to the project

Act	Responsible Authority	Approval/Permit	Trigger	Applicability	Timing
<b>Commonwealth legislation</b>					
<p><i>Environment Protection and Biodiversity Conservation Act 1999</i> (EPBC Act)</p>	<p>Commonwealth Department of the Environment and Energy (DoEE)</p>	<p>EPBC Act referral to Department of Environment and Energy for determination on whether the proposal is a 'controlled action', 'Controlled action – Particular Manner' or 'Not a Controlled Action'.</p>	<p>Undertaking an action that will have or may have a significant impact on MNES. Undertaking an action that will have a significant impact on the environment on Commonwealth land</p>	<p>The EPBC Act regulates activities that have the potential to impact on matters of national environmental significance (MNES) and actions undertaken on Commonwealth land and by Commonwealth agencies. Relevant MNES to this project include:</p> <ul style="list-style-type: none"> <li>Threatened fauna species, and;</li> <li>Commonwealth heritage sites</li> </ul> <p>Due to the disturbed nature of the project area (in varying degrees from completely cleared to partially disturbed), there is a generally low likelihood that threatened species and threatened ecological communities occur within the sites (threatened species likely to be only transitory). As such, the works are not expected to have a significant impact to MNES. However, it is recommended that pre-clearing surveys be conducted to confirm the presence of MNES and whether EPBC referral is required, particularly sites containing better quality native vegetation and habitat. Survey works will need to include more targeted fauna surveys to identify if any threatened species are nesting within the project footprint, including any operational. It is also understood that DITCRD is progressing a Strategic Assessment for Christmas Island. There may be opportunities to include the replacement, maintenance and operation of the rockfall mitigation structures in the scope of this Strategic Assessment.</p>	<p>1-12 months depending. Referral fee will apply. Assessment costs depending.</p>

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Act	Responsible Authority	Approval/Permit	Trigger	Applicability	Timing
<i>Environment Protection and Biodiversity Conservation Regulations (EPBC Regulation)</i>	Commonwealth Department of the Environment and Energy (DoEE)	Part 9 approval under the EPBC Regulation	An action that results in the death or injury of a protected species. Vegetation clearing for the access road or the construction of a new flexible barrier may impact on protected fauna nesting or the migration of Red Crabs	Schedule 12 of the EPBC regulations defines all flora and fauna on Christmas Island as protected. In the case of a "Not Controlled Action (NCA)" decision under the EPBC Act, a permit under Part 9 of the EPBC Regulations is required. This permit is necessary to approve an activity which has the potential to kill, injure or take, or damage or destroy a nest or dwelling place of a member of a protected species on Christmas Island (refer Schedule 12 of the EPBC Regulations 2000).	
<b>Western Australian legislation</b>					
<i>Environmental Protection Act 2004, Environmental Protection (Clearing of Native Vegetation) Regulations 2004</i>			A clearing permit process, under the <i>Environmental Protection (Clearing of Native Vegetation) Regulations 2004 (WA)</i> , is required when: <ul style="list-style-type: none"> <li>The area to be cleared is greater than 5 hectares and/or is constrained by the presence of an Environmentally Sensitive Areas (ESA), or;</li> <li>The purpose for which the clearing is to be completed is not a prescribed or exempt activity.</li> </ul>	ESAs are defined in the Western Australian Government Gazette, and there are no sites listed for Christmas Island. It is unlikely that greater than 5ha of clearing may be required for the access track and any maintenance for the fencing, however this will be confirmed during detailed design.	3-6 months

## 5.2 Approvals required

This report does not provide a legal opinion on the applicability of specific legislation and the triggering of associated approvals. The recommendations are based on the interpretation of available materials, legislation and information provided.

In summary, the following approvals are anticipated to be required:

- Referral under the EPBC Act and potential approval for impacts to:
  - Commonwealth heritage place
  - Threatened fauna species;
- Referral under the EPBC Act for impacts to the environment associated with work carried out on Commonwealth land by a Commonwealth agency;
- Part 9 permit under the EPBC Regulations, and;
- Clearing permit under the *WA Environmental Protection Act*

**Table 3** details the approvals required to carry out the proposed works. Achieving such approvals will require technical supporting information that assesses the projects potential impacts upon environmental factors and outlines appropriate means to mitigate the effects of such impacts.

Table 3: Approvals likely to be required for the works

Activity	Legislation/Policy	Approval	Approving Authority	Estimated assessment timeframe
Vegetation clearing, access road and flexible barrier construction	EPBC Act	Referral and controlled action determination	Department of Environment and Energy	1 month for controlled action  6-12 months for approval if required
	EPBC Regulation	Permit under Part 9	Department of Environment and Energy	3-6 months
Vegetation clearing	EP Act	Clearing permit	WA Environ	3-6 months

The following information will need to be collated when submitting all permit applications:

- Concept, preliminary or detailed design drawings;
- Ecological and heritage field investigations;
- Impact assessment and recommended mitigation measures;
- Details of construction methodology, and
- Relevant forms.

## 6 Impacts and recommended mitigation measures

This section provides a summary of the identified impacts identified during the development of the concept design. At this stage the identified mitigation measures are focused on those that can be addressed in the future design phases (Table 4).

Table 4: Concept design impacts and recommended mitigation measures

Element	Potential impacts	Recommendation mitigation measures
Soils and geology	Disturbance of vegetation cover to expose soils	<ul style="list-style-type: none"> <li>Detailed design to utilise the existing construction footprint;</li> <li>Consider revegetation strategy to include planting of native species to achieve rapid cover of exposed soils, and;</li> <li>Development of an erosion and sediment control plan to be implemented during construction.</li> </ul>
Biodiversity	Clearing of vegetation for access tracks	<ul style="list-style-type: none"> <li>Design to utilise the footprint for the existing fences that are to be removed;</li> <li>Access road detailed design to minimise clearing of native vegetation and utilise existing cleared corridor;</li> <li>Preparation of a Vegetation Management Plan to be implemented during construction that sets out how vegetation clearing works will be completed and how retained vegetation will be protected.</li> <li>Detailed design to consider location of large trees in rainforest communities and the placement of footings to protect root zones.</li> </ul>
	Clearing of vegetation for maintenance and operation	<ul style="list-style-type: none"> <li>Design to include a plan for the slashing and removing vegetation as part of the maintenance strategy required, and;</li> <li>Any revegetation proposed should include native flora species, with consideration for the maintenance requirements to keep the fence free of vegetation.</li> </ul>
	Impacts to threatened fauna	<ul style="list-style-type: none"> <li>Targeted ecological to be carried out during detailed design phase to identify any threatened fauna or important habitat for threatened fauna;</li> </ul>

Element	Potential impacts	Recommendation mitigation measures
		<ul style="list-style-type: none"> <li>• Preparation of a Fauna Management Plan that identifies habitat resources for fauna, location of any nesting resources and procedures for managing</li> <li>• Fauna spotter/catcher to carry out pre-clearing survey</li> </ul>
	Red crab migration	<ul style="list-style-type: none"> <li>• Detailed design to explore options to allow crab movements through, over or under the fence, provided the function of the fence to mitigate rock fall is not compromised, and;</li> <li>• Development of an operational phase management plan to inform residents of the need to maintain the fence in its condition.</li> <li>• Construction to occur outside of the crab migration season</li> </ul>
Heritage	Direct impacts to Malay cemetery	<ul style="list-style-type: none"> <li>• Heritage or archaeological survey to map the actual, on-ground extent of the Malay cemetery site;</li> <li>• If required, preparation of a Cultural Heritage Management Plan to outline how areas on the Commonwealth Heritage Register are protected</li> <li>• Development of procedures to be included in the Construction Environmental Management Plan for the management of disturbed, previously unrecorded cultural heritage, and;</li> <li>• During detailed design, ensure placement of fences avoid impacts to the actual cemetery site.</li> </ul>
Noise and vibration	Construction noise and vibration impacts to adjacent residents	<ul style="list-style-type: none"> <li>• Management of noise and vibration will need to be considered during construction to minimise impact to sensitive receivers, with measures included in a Construction EMP.</li> <li>• Condition assessments are recommended for the heritage listed Malay Cemetery to assess if vibration may impact the site.</li> </ul>

## Appendix C

### Debris Flow and Rockfall Analysis

# C1 Landslide Magnitude Frequency Assessment

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<b>ARUP</b> Ove Arup & Partners Hong Kong Limited Calculation Sheet	Sheet No:	2	Rev:	0	Job No:	208575	
	Job Title:	Xmas Island Landslide Magnitude Frequency Review	Input by:	SWM	Checked by:	SWM	Date:
Subject: Quantitative Risk Assessment - Magnitude Frequency Assessment							

**Landslide Annual Frequency versus Volume**

Landslide Volume (v)	Log v	12000 Years		2000 Years		100 Years		50 Years		30 Years		10 Years		N <sub>v</sub>
		No. of LS	Annual Freq.	No. of LS	Annual Freq.	No. of LS	Annual Freq.	No. of LS	Annual Freq.	No. of LS	Annual Freq.	No. of LS	Annual Freq.	
10.00	1.00	9	0.001	9	0.005	9	0.090	6	0.120	6	0.200	6	0.600	2.628
15.85	1.20	8	0.001	8	0.004	8	0.080	5	0.100	5	0.167	5	0.500	1.871
25.12	1.40	8	0.001	8	0.004	8	0.080	5	0.100	5	0.167	5	0.500	1.082
39.81	1.60	8	0.001	8	0.004	8	0.080	5	0.100	5	0.167	5	0.500	0.673
63.10	1.80	7	0.001	7	0.004	7	0.070	4	0.080	4	0.133	4	0.400	0.428
100.00	2.00	7	0.001	7	0.004	7	0.070	4	0.080	4	0.133	4	0.400	0.268
158.49	2.20	6	0.001	6	0.003	6	0.060	3	0.060	3	0.100	3	0.300	0.167
251.19	2.40	5	0.000	5	0.003	5	0.050	2	0.040	2	0.067	2	0.200	0.103
398.11	2.60	4	0.000	4	0.002	4	0.040	2	0.040	2	0.067	2	0.200	0.062
630.96	2.80	3	0.000	3	0.002	3	0.030	2	0.040	2	0.067	2	0.200	0.036
1000.00	3.00	2	0.000	2	0.001	2	0.020	1	0.020	1	0.033	1	0.100	0.019
1584.89	3.20	1	0.000	1	0.001	1	0.010	1	0.020	1	0.033	1	0.100	0.010
2511.89	3.40	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.005
3981.07	3.60	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.002
6309.57	3.80	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	-0.001
10000.00	4.00	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	-0.002
15848.93	4.20	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.000
25118.86	4.40	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.000
39810.72	4.60	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.000
63095.73	4.80	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.000

**Formula and Parameters used to define Mf Curve**

N <sub>v</sub> min:	25.00	v <sub>max</sub> :	3000.00
Gradient, β:	2.25	v <sub>min</sub> :	1.00

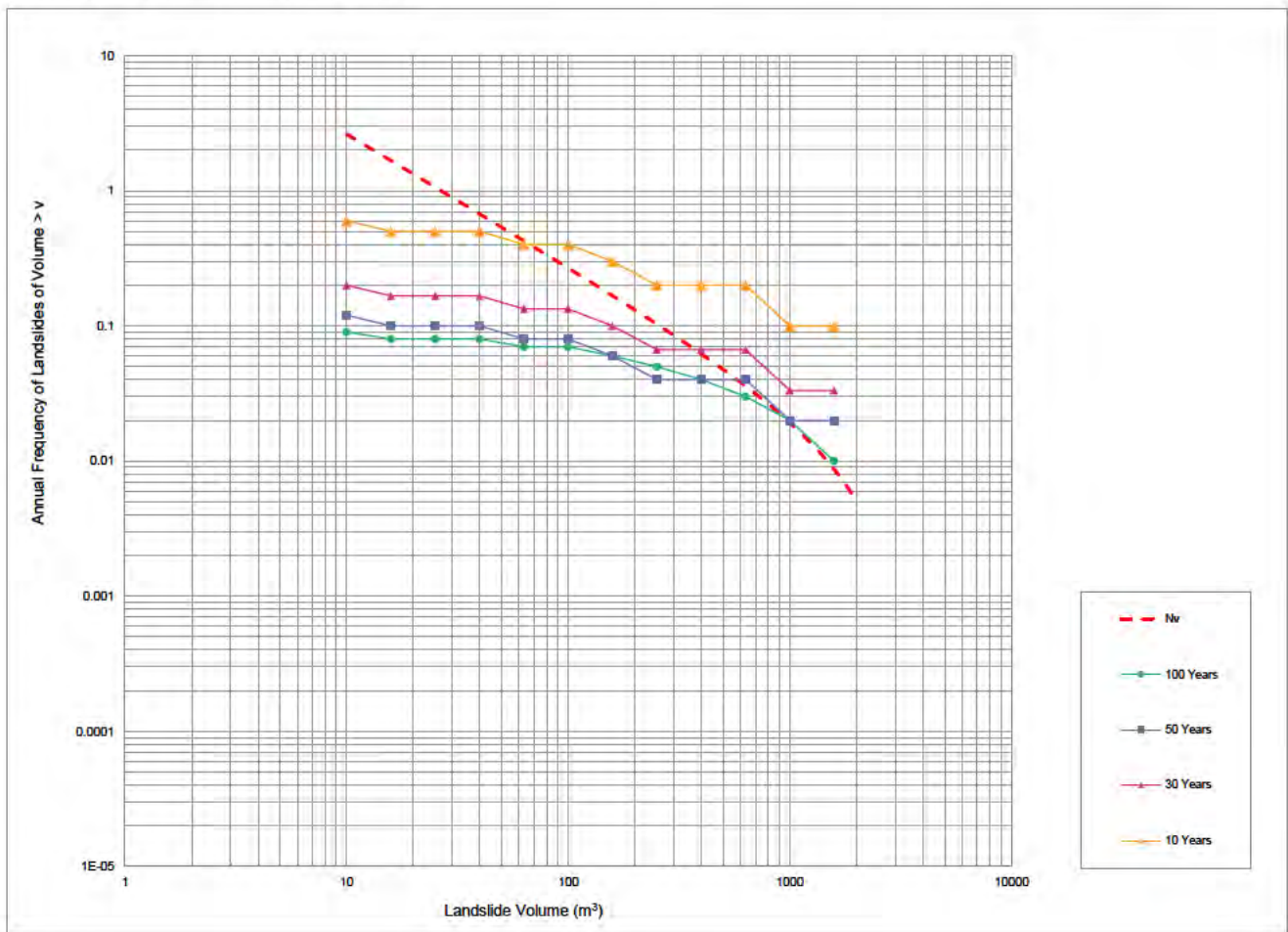
log<sub>10</sub> v<sub>max</sub> : 3.4771  
 log<sub>10</sub> v<sub>min</sub> : 0.0000

Where,

- N<sub>v</sub> = Cumulative annual frequency of a landslide with volume ≥ v
- N<sub>v</sub> min = Cumulative annual frequency of a landslide with the minimum landslide volume, v<sub>min</sub>
- β = Slope of the landslide versus frequency relationship
- v = Landslide volume
- v<sub>min</sub> = Minimum landslide volume
- v<sub>max</sub> = Maximum credible landslide for the catchment

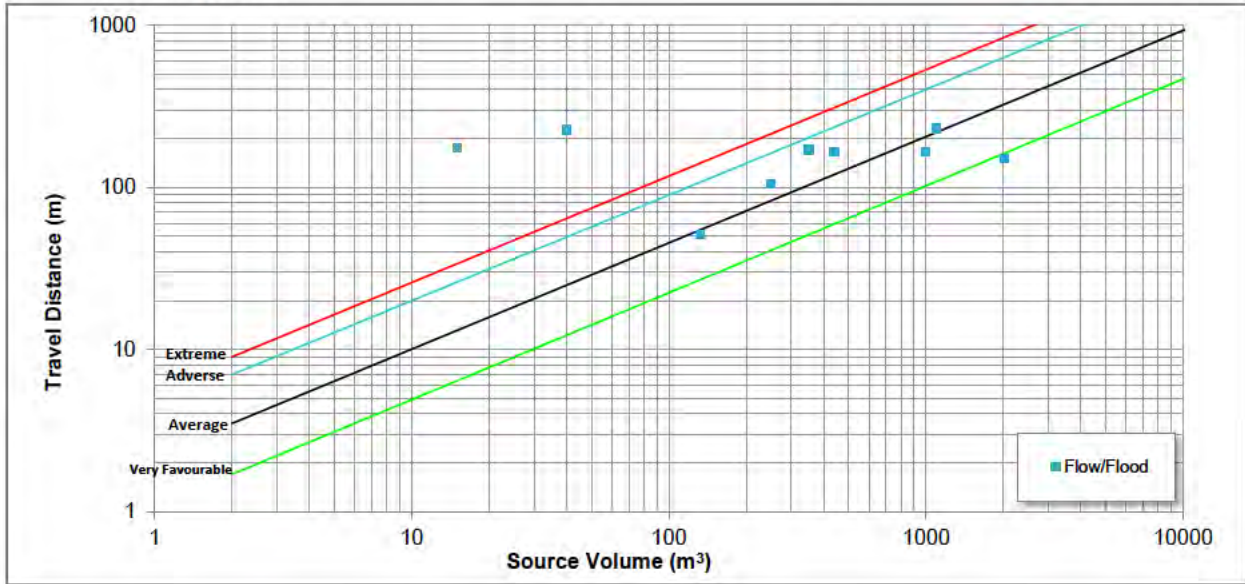
$$N_v = \frac{N_{v_{min}} [e^{-\beta(\log_{10} v - \log_{10} v_{min})} - e^{-\beta(\log_{10} v_{max} - \log_{10} v_{min})}]}{[1 - e^{-\beta(\log_{10} v_{max} - \log_{10} v_{min})}]}$$

**Landslide Annual Frequency versus Volume (by Year)**

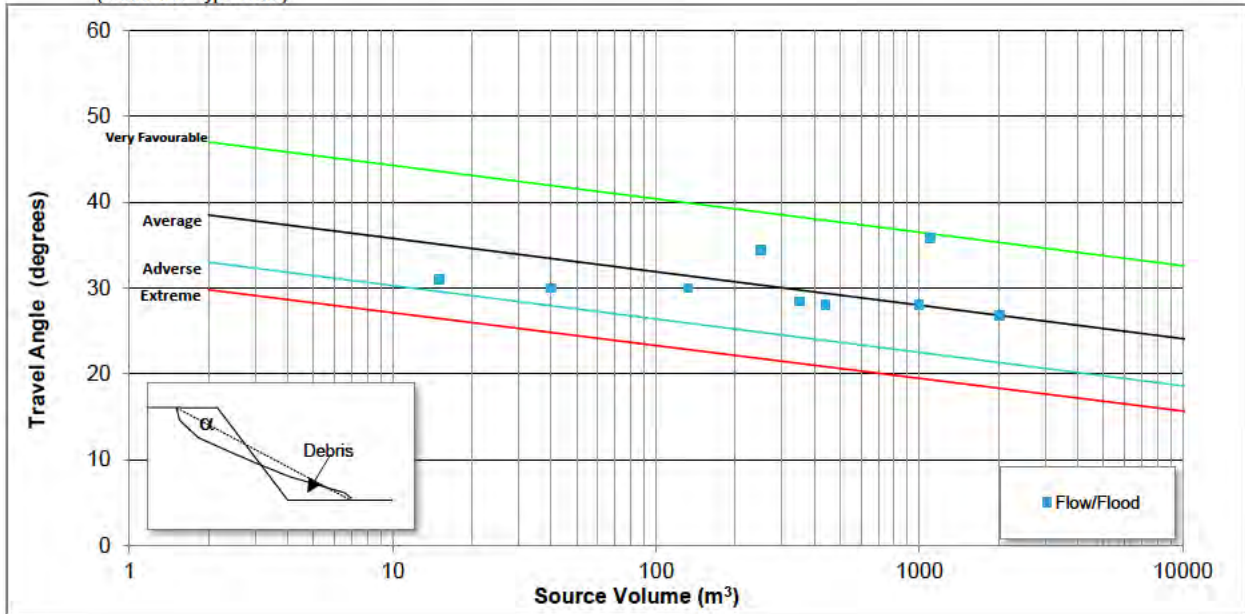


<b>ARUP</b> Ove Arup & Partners Hong Kong Limited Calculation Sheet	Sheet No: 3	Rev: 0	Job No: 268575
	Job Title: Xmas Island Landslide Magnitude Frequency Review	Input by: SWM	Checked by: SWM
Subject: Quantitative Risk Assessment - Risk Summation			

**Travel Distance versus Volume** (after GEO Report 174)  
 (Landslide Type Data)



**Angle of Reach versus Volume** (after GEO Report 174)  
 (Landslide Type Data)





Ove Arup & Partners Hong Kong Limited  
Calculation Sheet

Sheet No: 4

Rev: 0

Job No: 268575

Job Title: LPMit Programme 2008, Package N, Natural Terrain  
Hazard Mitigation Works, West Lantau, Agreement  
CE62/2008 (GE)

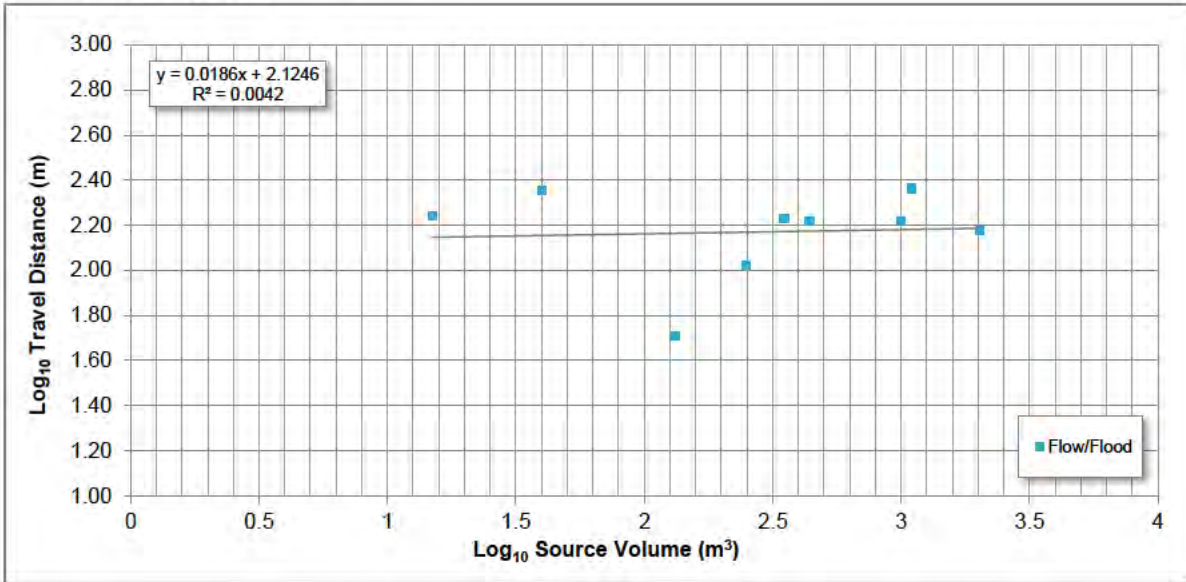
Input by: SWM

Checked by: SWM

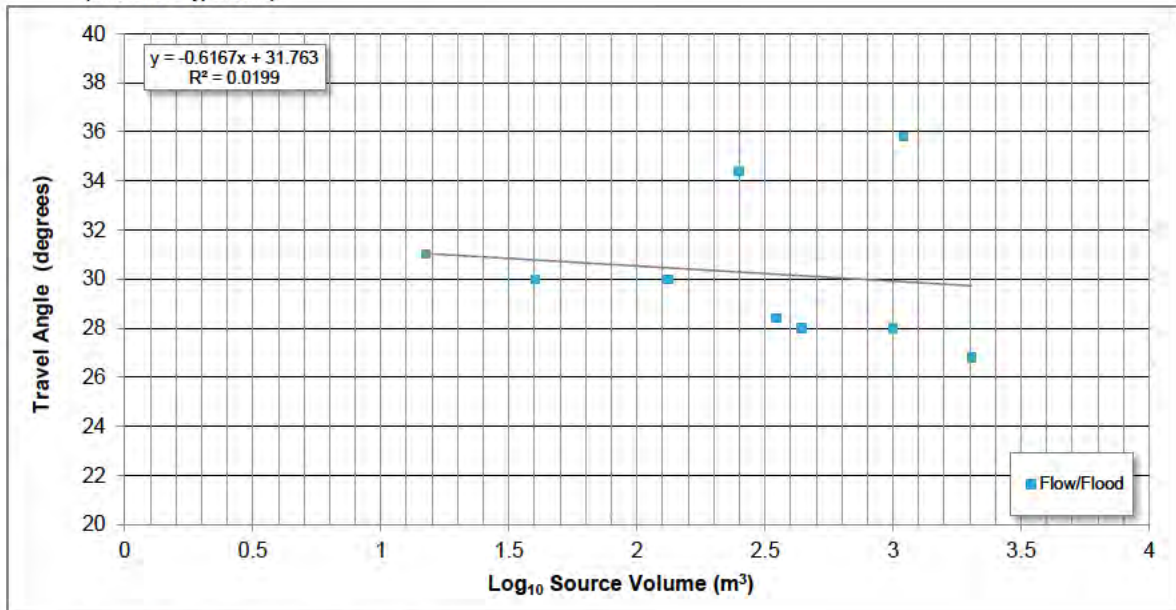
Date: Jun-19

Subject: Quantitative Risk Assessment - Risk Summation

**Travel Distance versus Volume**  
(Landslide Type Data)



**Angle of Reach versus Volume**  
(Landslide Type Data)



**Best-fit Regression Line (GIS Program Input)**

**TRAVEL DISTANCE**

$\text{Log (Flow/Flood)} = \boxed{2.3617} + \boxed{3.3064} \log_{10}(\text{Volume})$       Standard deviation (SD) =   
 $\text{Log (Avalanche)} = \boxed{\phantom{000000}} + \boxed{\phantom{000000}} \log_{10}(\text{Volume})$       Standard deviation (SD) =

**ANGLE OF REACH**

$\text{Flow/Flood} = \boxed{35.8000} - 2^{\circ}\text{SD} + \boxed{3.3064} \log_{10}(\text{Volume})$       Standard deviation (SD) =   
 $\text{Avalanche} = \boxed{\phantom{000000}} - 2^{\circ}\text{SD} + \boxed{\phantom{000000}} \log_{10}(\text{Volume})$       Standard deviation (SD) =

## C2 Landslide Back Analysis

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Ove Arup & Partners Hong Kong Ltd.

**CALCULATION SHEET - DAN-W DEBRIS FLOW ANALYSIS**

<b>JOB TITLE</b>	Christmas Island Debris Flows	
<b>JOB NUMBER</b>	268575	
<b>REPORT TITLE</b>	Back Analysis of Landslides in Christmas Island	<b>Initial</b>
<b>MADE BY</b>	Mike Sham	MS
<b>CHECKED BY</b>	Arthur Cheung	AC
<b>APPROVED BY</b>	Jack Yiu	JY
<b>DATE</b>	June 2019	

**CONTENTS OF SPREADSHEET**

Section	Description	Sheet No.
<b>1.0</b>	<b>INTRODUCTION</b>	1
<b>2.0</b>	<b>METHOD OF ANALYSES</b>	1
2.1	DAN-W Software	1
2.2	Assumptions for DAN-W Software	1
2.3	Back Analysis vs. Predictive Approach	1
2.4	Material Properties	1
<b>3.0</b>	<b>DEBRIS MOBILITY ANALYSIS</b>	2
3.1	Summary of Analysis Input Parameters and Results	2
3.2	Details of Analysis Results	3 to 8
Annex A	DAN/W Modelling Output Sheets	9

**REVISIONS:** Current Revision:

Rev.	Date	Made by	Check	Description
0	June 2019	MS	AC	

<b>ARUP</b>		<b>JOB TITLE:</b> Christmas Island Debris Flows			
		<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b>		Analysis Summary
<b>Sheet No.:</b> 2	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

**3.0 DEBRIS MOBILITY ANALYSIS**

**3.1 Summary of Analysis Input Parameters and Results**

Hazard Type/ID	Landslide ID	3	5	6
	Name	Basketball Court Landslide	412 Landslide	Boat Club Landslide, 2017
	Source Morphology	Sheet	Spoon	Sheet
	Hazard Type	OHL	OHL	OHL
Source Area Geometry	Slope Length (m)*	40	10	40
	Slope Width (m)*	21	5	25
	Failure Depth (m)*	1.5	1.5	2
Failure Volume	Estimated Source Volume (m³)*	1250	40	2000
	Computed Source Volume (m³)	1257.00	44.66	2005.00
	Estimated Entrainment Vol. (m³)	0.00	0.00	0.00
	Computed Entrainment Vol. (m³)	0.00	0.00	0.00
	Total Debris Volume (m³)	1257.00	44.66	2005.00
Run-out characteristics	Run-out Distance (from detailed field mapping) (m)	105	173	110
	Computed Run-out Distane (m)	104	176	121
	Estimated Total Debris Volume passing OP (m³)	27	10	700
	Computed Total Debris Volume passing OP (m³)	37	13	718
	Maximum Debris Thickness (m)	2.14	1.53	3.4
	Maximum Debris Thickness at OP (m)	0.66	0.12	1.50
	Maximum Debris Velocity (m/s)	12.95	18.45	12.47
	Maximum Debris Velocity at OP (m/s)	5.89	11.69	12.18
Input Frictional Parameters	Chainage (m)	0-277	0-289	0-196
	Friction Angle (°)	31	32	26

**Hazard Type**

OHL - Open Hillside Landslide

**Run-out Characteristics**

OP - Observation Point

**ADDITIONAL COMMENTS:**

OP: Location of existing Rockfall Barrier

\*See below for reference of volume calculations from landslide dimensions

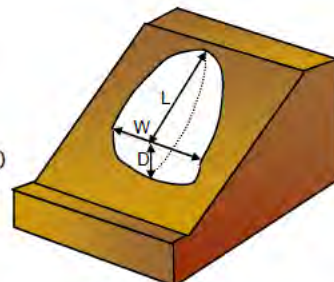
**CALCULATIONS**

Total Volume = Source Volume + Entrainment Volume

Sheet - Landslide Source Volume =  $L \times W \times D$

Spoon - Landslide Source Volume =  $\frac{1}{6} \pi(L \times W \times D)$

L -	Length
W -	Width
D -	Depth



<b>ARUP</b>	<b>JOB TITLE:</b>	Christmas Island Debris Flows									
	<b>JOB NUMBER:</b>	268575	<b>SHEET DESCRIPTION:</b>	Analysis Introduction and Description							
<b>Sheet No.:</b>	1	<b>Date:</b>	June 2019	<b>Drawn:</b>	MS	<b>Checked:</b>	AC	<b>Approved:</b>	JY	<b>Revision:</b>	0

## 1.0 INTRODUCTION

The mobility of potential landslides within the study area has been assessed based on the hazard models generated and the predicted Design Events for each catchment.

## 2.0 METHOD OF ANALYSES

### 2.1 **DAN-W Software**

The analysis has been carried out using the computer programme DAN/W developed by O. Hungr Geotechnical Research Inc. This is a windows based programme used to model post failure motion of rapid landslides. It implements a Lagrangian solution of the equations of motion for a mass of earth material which starts from a prescribed static configuration and flows according to one of several rheological relationships.

The critical section(s) for the analysis were identified based on detailed field mapping. The debris flow length, width, inclination and runout profile were estimated based on field mapping records.

No termination criteria was applied to the model and it was allowed to run until the debris had ceased to move as a result of its own properities.

### 2.2 **Assumptions for DAN-W Software**

- The material unit weight has been assumed to be 19 kN/cu.m for all analysis
- The material friction coefficient has been back-analysed
- The material internal friction angle has been assumed to be 35 degrees for all analysis
- The pore pressure coefficient (Ru) has been set as zero for all analysis
- For a Frictional Rheology analysis, the only variable is the Friction Angle
- For a Voellmy Rheology analysis, both the Friction Coefficient (dimensionless) and Turbulence Coefficient (m/s<sup>2</sup>) are variable parameters
- A cross-sectional shape factor of 0.67 has been appied to represent flow along a non-circular channel
- Cross-sectional profiles have been determined based on Field Mapping Data

### 2.3 **Back Analysis**

In the back-analysis, the variable are material friction coefficient, turbulence coefficient and entrainment thickness.

### 2.4 **Material Properties**

The rheology is defined by the landslide or hazard type. An Open Hillside Landside (OHL) will be modelled using a 'Frictional' rheology whereas Debris Flow (DF) with TD catchment and Channelised Debris Flow (CDF) within CD catchment will be modelled using a 'Voellmy' rheology.

The parameters specified in the Material Properties table are defined by the rheological model used. Friction Angle only applies to Frictional models. Friction Coefficient, Turbulence Coefficient and Erosion Depth only apply to Voellmy models.

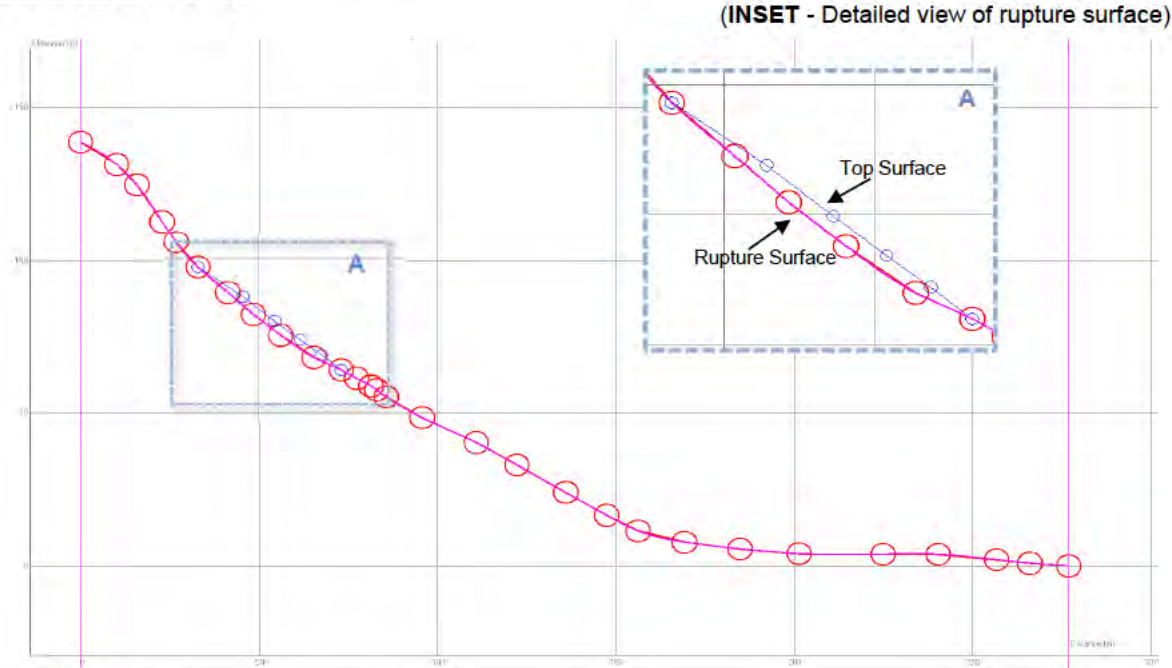
<b>ARUP</b>	<b>JOB TITLE:</b> Christmas Island Debris Flows				
	<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Input Parameters			
<b>Sheet No.:</b> 3	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

3.2 cont' Details of Analysis Results

Landslide ID: 3  
 Hazard Type: OHL

Estimated Source Volume: 1250.00 m<sup>3</sup>  
 Estimated Entrainment Volume: 0 m<sup>3</sup>

**SECTIONAL PROFILE**



**WIDTH PROFILE**



**MATERIAL PROPERTIES**

Chainage (m)	Rheology	Unit Weight (kN/m <sup>3</sup> )	Friction Angle (°)	Pore Pressure Coefficient	Friction Coefficient	Turbulence Coefficient (m/s <sup>2</sup> )	Internal Angle of Friction (°)	Erosion Depth (m)
0-277	Frictional	19	31	-	-	-	35	0

**NOTE:** See Section 2.4 for explanation of Material Properties

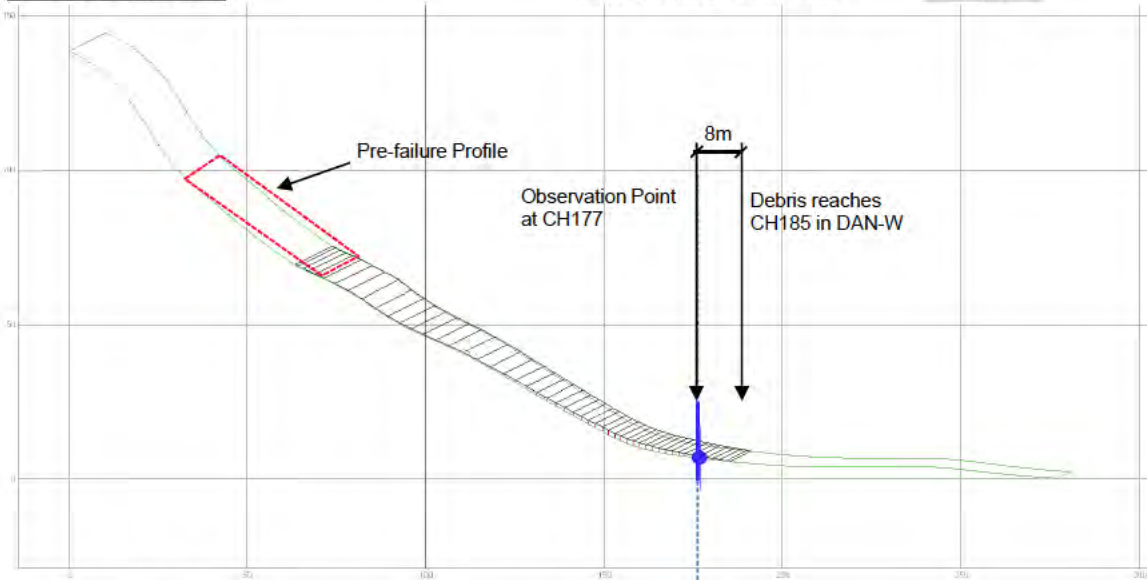
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		<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Output Results		
<b>Sheet No.:</b> 4	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

Failure ID: 3  
 Hazard Type: OHL

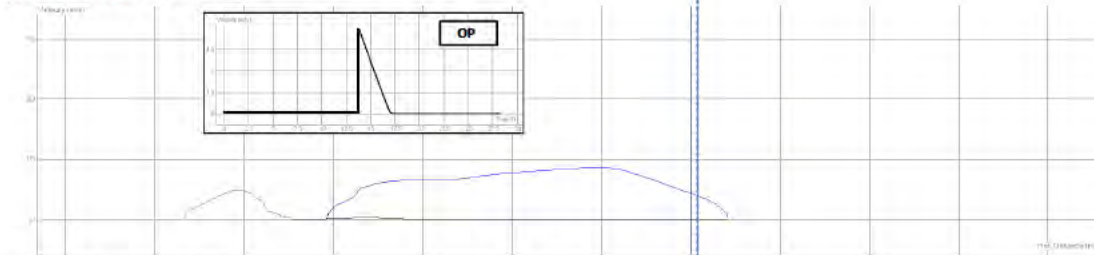
**DEBRIS VOLUME**

Computed Source Volume: 1257.00 m<sup>3</sup>  
 Computed Entrainment: 0.00 m<sup>3</sup>

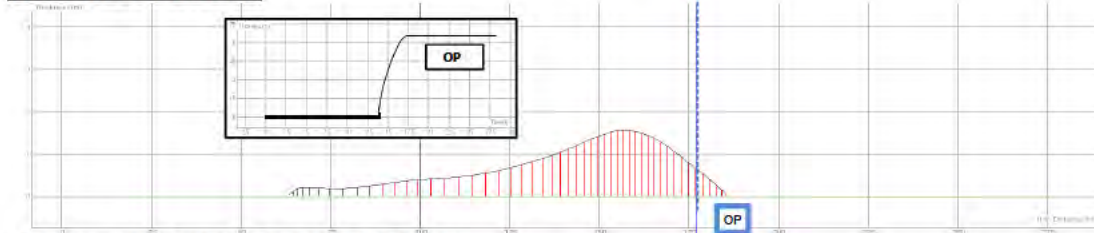
**FAILURE PROFILE**



**VELOCITY PROFILE**



**THICKNESS PROFILE**



**DEBRIS RUN-OUT CHARACTERISTICS**

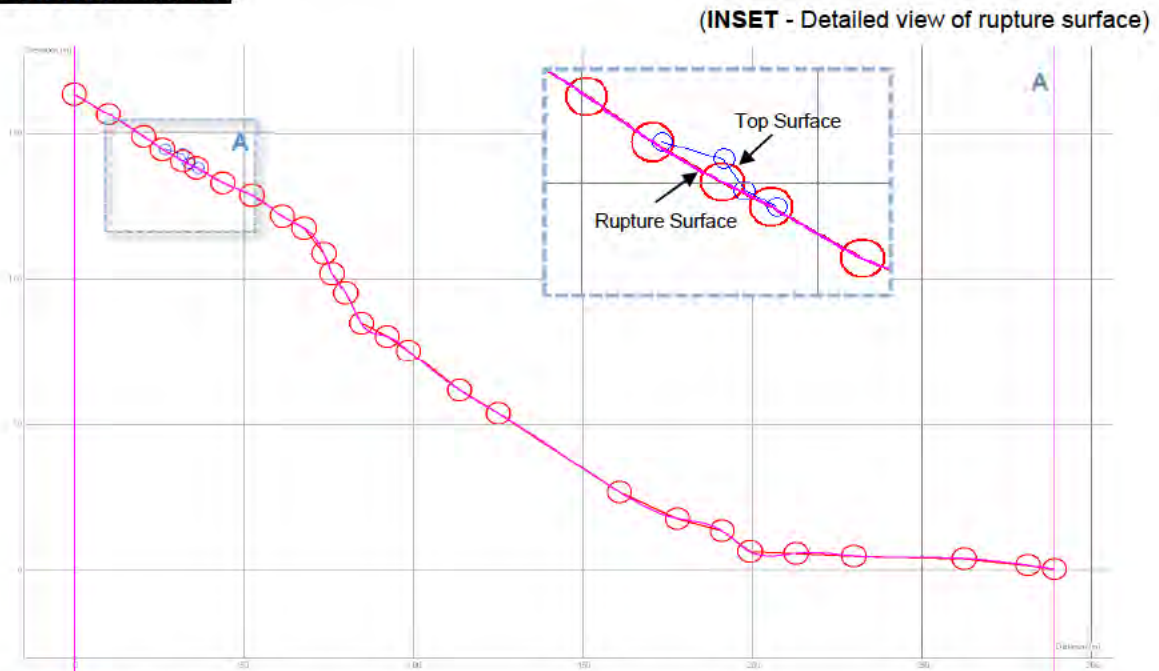
	Run-out	OP
Total Computed Debris Volume (m <sup>3</sup> )	1257.00	
Total Debris Volume passing OP		37
Maximum Debris Thickness (m)	2.14	0.66
Maximum Debris Velocity (m/s)	12.95	5.89

<b>ARUP</b>	<b>JOB TITLE:</b> Christmas Island Debris Flows				
	<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Input Parameters			
<b>Sheet No.:</b> 5	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

3.2 cont' Details of Analysis Results

Landslide ID	5	Estimated Source Volume	40.00 m <sup>3</sup>
Hazard Type	OHL	Estimated Entrainment Volume	0 m <sup>3</sup>

**SECTIONAL PROFILE**



**WIDTH PROFILE**



**MATERIAL PROPERTIES**

Chainage (m)	Rheology	Unit Weight (kN/m <sup>3</sup> )	Friction Angle (°)	Pore Pressure Coefficient	Friction Coefficient	Turbulence Coefficient (m/s <sup>2</sup> )	Internal Angle of Friction (°)	Erosion Depth (m)
0-289	Frictional	19	32	-	-	-	35	0

**NOTE:** See Section 2.4 for explanation of Material Properties

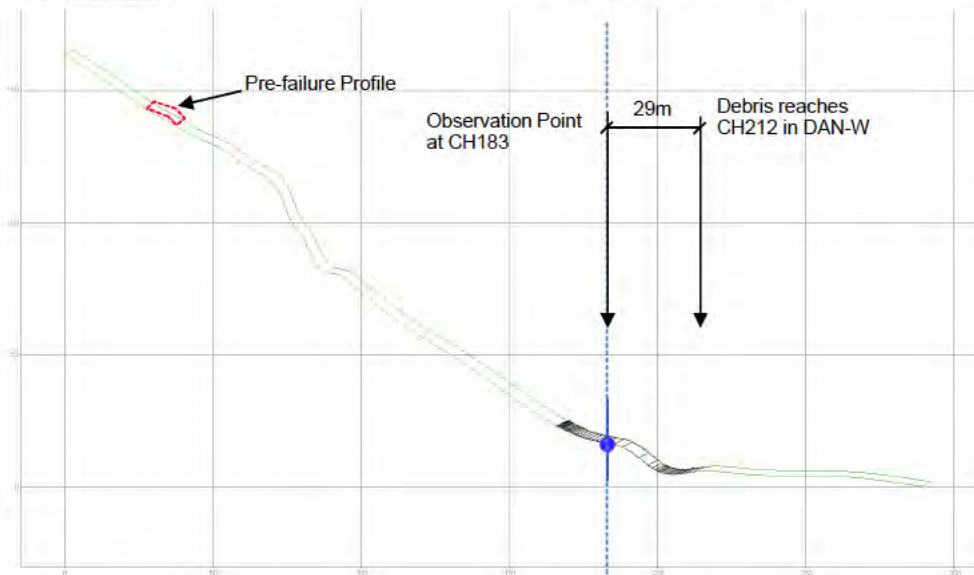
<b>ARUP</b>		<b>JOB TITLE:</b> Christmas Island Debris Flows			
		<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Output Results		
<b>Sheet No.:</b> 6	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

Failure ID: 5  
 Hazard Type: OHL

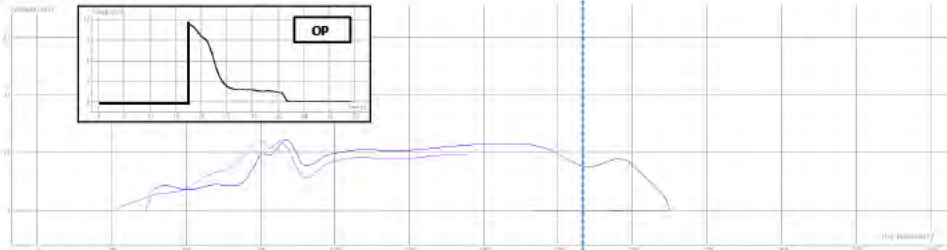
**DEBRIS VOLUME**

Computed Source Volume: 44.66 m<sup>3</sup>  
 Computed Entrainment: 0.00 m<sup>3</sup>

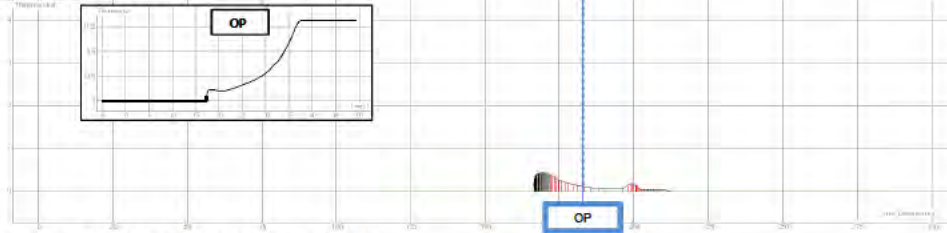
**FAILURE PROFILE**



**VELOCITY PROFILE**



**THICKNESS PROFILE**



**DEBRIS RUN-OUT CHARACTERISTICS**

	Run-out	OP
Total Computed Debris Volume (m <sup>3</sup> )	44.66	
Total Debris Volume passing OP		12.62
Maximum Debris Thickness (m)	1.53	0.12
Maximum Debris Velocity (m/s)	18.45	11.69

# ARUP

**JOB TITLE:** Christmas Island Debris Flows

**Sheet No.:** 7

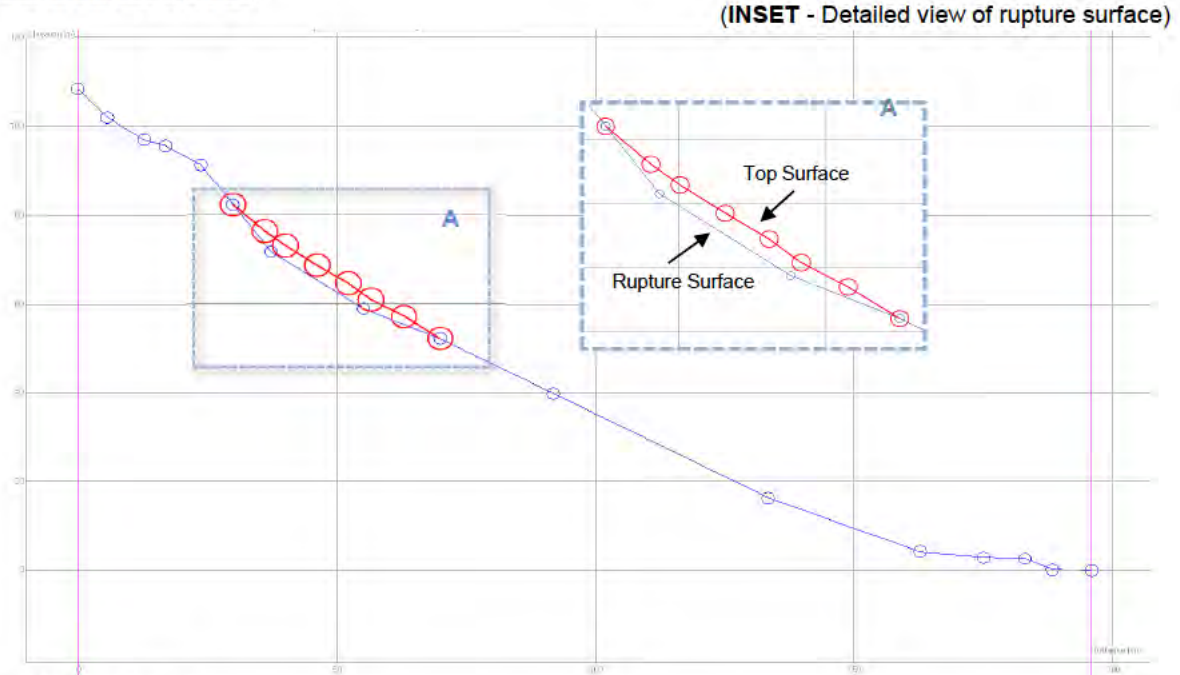
**JOB NUMBER:** 268575 **SHEET DESCRIPTION:** Input Parameters

**Date:** June 2019 **Drawn:** MS **Checked:** AC **Approved:** JY **Revision:** 0

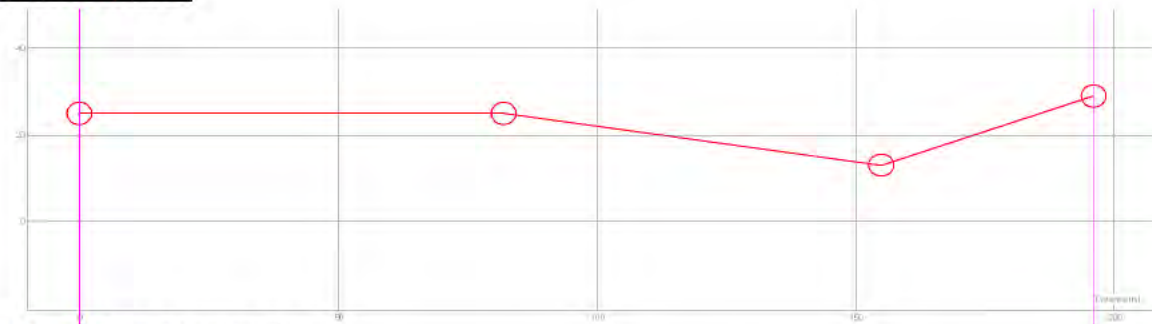
### 3.2 cont' Details of Analysis Results

Landslide ID: 6  
 Hazard Type: OHL  
 Estimated Source Volume: 2000 m<sup>3</sup>  
 Estimated Entrainment Volume: 0 m<sup>3</sup>

#### SECTIONAL PROFILE



#### WIDTH PROFILE



#### MATERIAL PROPERTIES

Chainage (m)	Rheology	Unit Weight (kN/m <sup>3</sup> )	Friction Angle (°)	Pore Pressure Coefficient	Friction Coefficient	Turbulence Coefficient (m/s <sup>2</sup> )	Internal Angle of Friction (°)	Erosion Depth (m)
0-196	Frictional	19	26	0	-	-	35	0

**NOTE:** See Section 2.4 for explanation of Material Properties

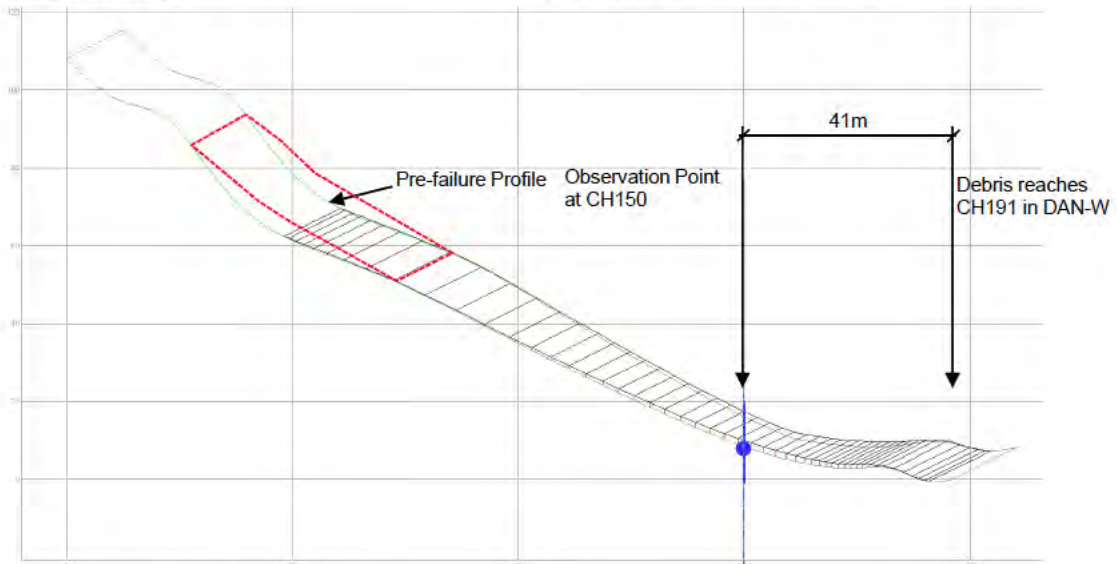
<b>ARUP</b>		<b>JOB TITLE:</b> Christmas Island Debris Flows				
		<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Output Results			
<b>Sheet No.:</b>	8	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

Failure ID: 6  
 Hazard Type: OHL

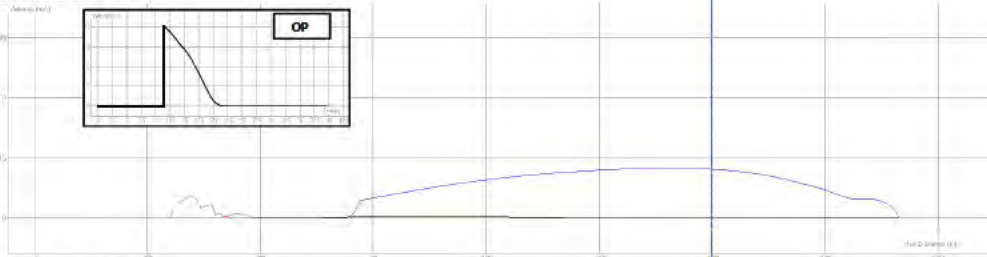
**DEBRIS VOLUME**

Computed Source Volume: 2005.00 m<sup>3</sup>  
 Computed Entrainment: 0.00 m<sup>3</sup>

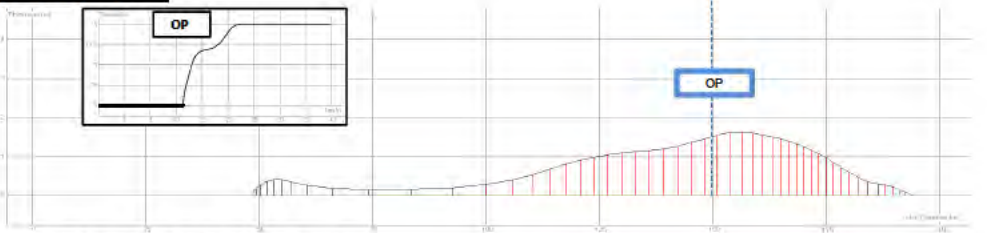
**FAILURE PROFILE**



**VELOCITY PROFILE**



**THICKNESS PROFILE**



**DEBRIS RUN-OUT CHARACTERISTICS**

Total Computed Debris Volume (m <sup>3</sup> )	Run-out	OP
Total Debris Volume passing OP	2005.00	717.71
Maximum Debris Thickness (m)	3.4	1.5
Maximum Debris Velocity (m/s)	12.47	12.18

<b>ARUP</b>		<b>JOB TITLE:</b> Christmas Island Debris Flows				
		<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Output Sheet			
<b>Sheet No.:</b>	9	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

**ANNEX A**  
**DAN/W Modelling Output Sheets**

## DNW-OUTPUT- Section 3.TXT

DAN-W Release 10

File: \\HKGNTS22\geo\Actual Job\OC1185\11-00 Calculations\02 - DANW\DAN-W  
Model\Back analysis\Section3\_revise.DNW

Project: Christmas Island Debris Flow Study  
Data Set: 3 - Basketball Court Landslide  
Input By: MS  
Date: 6/19/2019

## Vertical slices

## MATERIAL 1:

Name: 1.00  
Rheology: Frictional  
Unit Weight: 19.00  
Friction Angle: 31.00  
Pore Pressure Coeff., Ru: 0.00  
Erosion Depth: 0.00  
Internal Friction Angle: 35.00

No of Blocks = 50  
Time step = 0.001 seconds  
End at time = 28.26 seconds  
Configuration = 3 dimensional  
Boundary Block Geometry = Vertical  
Shape factor = 0.67

## FRONT (final position):

Horiz. Location = 185.46  
Curvilinear Displ.= 128.38  
Horiz. Displ. = 112.39

## REAR (final position):

Horiz. Location= 63.43  
Curvilinear Displ.= 41.33  
Horiz. Displ. = 30.43

## CENTRE OF GRAVITY:

X-Source = 53.88  
Z-Source = 78.57  
X-Depos. = 135.79  
Z-Depos. = 25.76  
CG Ratio = 0.64  
Travel angle = 32.81  
FAHRBOSCHUNG = 31.01

Maximum velocity = 12.95 at X = 148.94  
Maximum front velocity = 12.95 at X = 148.94

## SLIDE VOLUME:

Initial = 1256.37  
Final = 1256.37

## DNW-OUTPUT- Section 3.TXT

## AREA IN PLAN:

Initial = 841.29  
Final = 1994.77

## LENGTH:

Initial = 52.24  
Final = 139.29

## MAXIMUM THICKNESS:

Initial = 2.14  
Final = 1.57

Runout not completed, V-MAX = 0.41

## DNW-OUTPUT- Section 5.TXT

DAN-W Release 10

File: \\Hkgnts22\geo\Actual Job\OC1185\11-00 Calculations\02 - DANW\ DAN-W  
Model\Section5.DNW

Project: Christmas Island Debris Flow Study  
Data Set: 5 - 412 Landslide  
Input By: MS  
Date: 5/3/2019

## Vertical slices

## MATERIAL 1:

Name: 1.00  
Rheology: Frictional  
Unit Weight: 19.00  
Friction Angle: 32.10  
Pore Pressure Coeff., Ru: 0.00  
Erosion Depth: 0.00  
Internal Friction Angle: 35.00

No of Blocks = 50  
Time step = 0.001 seconds  
End at time = 49.18 seconds  
Configuration = 3 dimensional  
Boundary Block Geometry = Vertical  
Shape factor = 0.67

## FRONT (final position):

Horiz. Location = 212.31  
Curvilinear Displ.= 228.39  
Horiz. Displ. = 175.80

## REAR (final position):

Horiz. Location= 166.20  
Curvilinear Displ.= 188.74  
Horiz. Displ. = 139.39

## CENTRE OF GRAVITY:

X-Source = 30.86  
Z-Source = 141.31  
X-Depos. = 179.26  
Z-Depos. = 17.12  
CG Ratio = 0.84  
Travel angle = 39.92  
FAHRBOSCHUNG = 36.58

Maximum velocity = 18.45 at X = 83.80  
Maximum front velocity = 18.45 at X = 83.80

## SLIDE VOLUME:

Initial = 44.66  
Final = 44.66

## DNW-OUTPUT- Section 5.TXT

## AREA IN PLAN:

Initial = 58.26  
Final = 308.61

## LENGTH:

Initial = 11.46  
Final = 51.11

## MAXIMUM THICKNESS:

Initial = 1.53  
Final = 0.44

Runout not completed, V-MAX = 0.42

## DNW-OUTPUT- Section 6.TXT

DAN-W Release 10

File: \\Hkgnts22\geo\Actual Job\OC1185\11-00 Calculations\02 - DANW\DAN-W Model\Section6.DNW

Project: Christmas Island Debris Flow Study  
 Data Set: 5 - 412 Landslide  
 Input By: MS  
 Date: 5/3/2019

## Vertical slices

## MATERIAL 1:

Name: 1.00  
 Rheology: Frictional  
 Unit Weight: 19.00  
 Friction Angle: 26.10  
 Pore Pressure Coeff., Ru: 0.00  
 Erosion Depth: 0.00  
 Internal Friction Angle: 35.00

No of Blocks = 50  
 Time step = 0.001 seconds  
 End at time = 43.21 seconds  
 Configuration = 3 dimensional  
 Boundary Block Geometry = Vertical  
 Shape factor = 0.67

## FRONT (final position):

Horiz. Location = 191.13  
 Curvilinear Displ.= 133.88  
 Horiz. Displ. = 121.13

## REAR (final position):

Horiz. Location= 48.17  
 Curvilinear Displ.= 27.19  
 Horiz. Displ. = 18.17

## CENTRE OF GRAVITY:

X-Source = 47.55  
 Z-Source = 65.27  
 X-Depos. = 128.89  
 Z-Depos. = 21.34  
 CG Ratio = 0.54  
 Travel angle = 28.37  
 FAHRBOSCHUNG = 27.18

Maximum velocity = 12.47 at X = 140.55  
 Maximum front velocity = 12.47 at X = 140.55

## SLIDE VOLUME:

Initial = 2005.44  
 Final = 2005.44

## DNW-OUTPUT- Section 6.TXT

## AREA IN PLAN:

Initial = 1000.00  
 Final = 2956.41

## LENGTH:

Initial = 50.99  
 Final = 157.68

## MAXIMUM THICKNESS:

Initial = 3.40  
 Final = 1.56

Runout not completed, V-MAX = 0.49

## C3 Landslide Predictive Analysis

Released under the Freedom of Information Act 1982 by the Department of  
Infrastructure, Transport, Regional Development, Communications, Sport and the Arts

**ARUP**Ove Arup &  
Partners Hong  
Kong Ltd.**CALCULATION SHEET -  
DAN-W DEBRIS FLOW ANALYSIS**

<b>JOB TITLE</b>	Christmas Island Debris Flows	
<b>JOB NUMBER</b>	268575	
<b>REPORT TITLE</b>	Forward Analysis of Landslides in Christmas Island	<b>Initial</b>
<b>MADE BY</b>	Mike Sham	MS
<b>CHECKED BY</b>	Arthur Cheung	AC
<b>APPROVED BY</b>	Jack Yiu	JY
<b>DATE</b>	June 2019	

**CONTENTS OF SPREADSHEET**

Section	Description	Sheet No.
1.0	<b>INTRODUCTION</b>	1
2.0	<b>METHOD OF ANALYSES</b>	1
2.1	DAN-W Software	1
2.2	Assumptions for DAN-W Software	1
2.3	Back Analysis vs. Predictive Approach	1
2.4	Material Properties	1
3.0	<b>DEBRIS MOBILITY ANALYSIS</b>	2
3.1	Summary of Analysis Input Parameters and Results	2
3.2	Details of Analysis Results	3
Annex A	DAN/W Modelling Output Sheets	9

**REVISIONS:** Current Revision:

Rev.	Date	Made by	Check	Description
0	June 2019	MS	AC	

<b>ARUP</b>		<b>JOB TITLE:</b> Christmas Island Debris Flows		
		<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Analysis Introduction and Description	
<b>Sheet No.:</b> 1				
<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

## 1.0 **INTRODUCTION**

The mobility of potential landslides within the study area has been assessed based on the hazard models generated and the predicted Design Events for each catchment.

## 2.0 **METHOD OF ANALYSES**

### 2.1 **DAN-W Software**

The analysis has been carried out using the computer programme DAN/W developed by O. Hungr Geotechnical Research Inc. This is a windows based programme used to model post failure motion of rapid landslides. It implements a Lagrangian solution of the equations of motion for a mass of earth material which starts from a prescribed static configuration and flows according to one of several rheological relationships.

The critical section(s) for the analysis were identified based on detailed field mapping. The debris flow length, width, inclination and runout profile were estimated based on field mapping records.

No termination criteria was applied to the model and it was allowed to run until the debris had ceased to move as a result of its own properites.

### 2.2 **Assumptions for DAN-W Software**

- The material unit weight has been assumed to be 19 kN/cu.m for all analysis
- The material friction coefficient has been back-analysed
- The material internal friction angle has been assumed to be 35 degrees for all analysis
- The pore pressure coefficient (Ru) has been set as zero for all analysis
- For a Frictional Rheology analysis, the only variable is the Friction Angle
- For a Voellmy Rheology analysis, both the Friction Coefficient (dimensionless) and Turbulence Coefficient (m/s<sup>2</sup>) are variable parameters
- A cross-sectional shape factor of 0.67 has been applied to represent flow along a non-circular channel
- Cross-sectional profiles have been determined based on Field Mapping Data

### 2.3 **Back Analysis**

In the back-analysis, the variable are material friction coefficient, turbulence coefficient and entrainment thickness.

### 2.4 **Material Properties**

The rheology is defined by the landslide or hazard type. An Open Hillside Landside (OHL) will be modelled using a 'Frictional' rheology whereas Debris Flow (DF) with TD catchment and Channelised Debris Flow (CDF) within CD catchment will be modelled using a 'Voellmy' rheology.

The parameters specified in the Material Properties table are defined by the rheological model used. Friction Angle only applies to Frictional models. Friction Coefficient, Turbulence Coefficient and Erosion Depth only apply to Voellmy models.

<b>ARUP</b>	<b>JOB TITLE:</b> Christmas Island Debris Flows	
	<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Analysis Summary
<b>Sheet No.:</b> 2	<b>Date:</b> June 2019	<b>Drawn:</b> MS
<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

**3.0 DEBRIS MOBILITY ANALYSIS**

**3.1 Summary of Analysis Input Parameters and Results**

Hazard Type/ID	Landslide ID	A	B	E
	Name	Section A	Section B	Section E
	Source Morphology	Sheet	Sheet	Sheet
	Hazard Type	OHL	OHL	OHL
Source Area Geometry	Slope Length (m)*	45	45	45
	Slope Width (m)*	15	15	15
	Failure Depth (m)*	3.00	3.00	3.00
Failure Volume	Estimated Source Volume (m³)*	2000	2000	2000
	Computed Source Volume (m³)	2007.00	2002.00	2007.00
	Estimated Entrainment Vol. (m³)	0.00	0.00	0.00
	Computed Entrainment Vol. (m³)	0.00	0.00	0.00
	Total Debris Volume (m³)	2007.00	2002.00	2007.00
Run-out characteristics	Total Debris Volume passing OP (m³)	123	130	195
	Maximum Debris Thickness (m)	4.58	4.14	5.28
	Maximum Debris Thickness at OP (m)	0.87	1.32	1.16
	Maximum Debris Velocity (m/s)	8.12	8.88	10.13
	Maximum Debris Velocity at OP (m/s)	6.24	6.10	6.02
	Maximum Kinetic Energy at OP (kJ)	4629	4679	6825
Input Frictional Parameters	Chainage (m)	0-175	0-274	0-238
	Friction Angle (°)	29.5	29.5	29.5

**Hazard Type**

OHL - Open Hillside Landslide

**Run-out Characteristics**

OP - Observation Point

**ADDITIONAL COMMENTS:**

OP: Location of existing Rockfall Barrier

\*See below for reference of volume calculations from landslide dimensions

**CALCULATIONS**

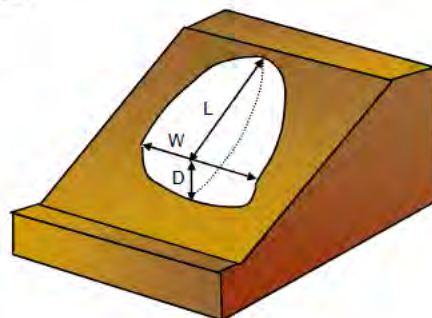
Total Volume = Source Volume + Entrainment Volume

Sheet - Landslide Source Volume = L x W x D

Spoon -

$$\text{Landslide Source Volume} = \frac{1}{6} \pi(L \times W \times D)$$

L -	Length
W -	Width
D -	Depth

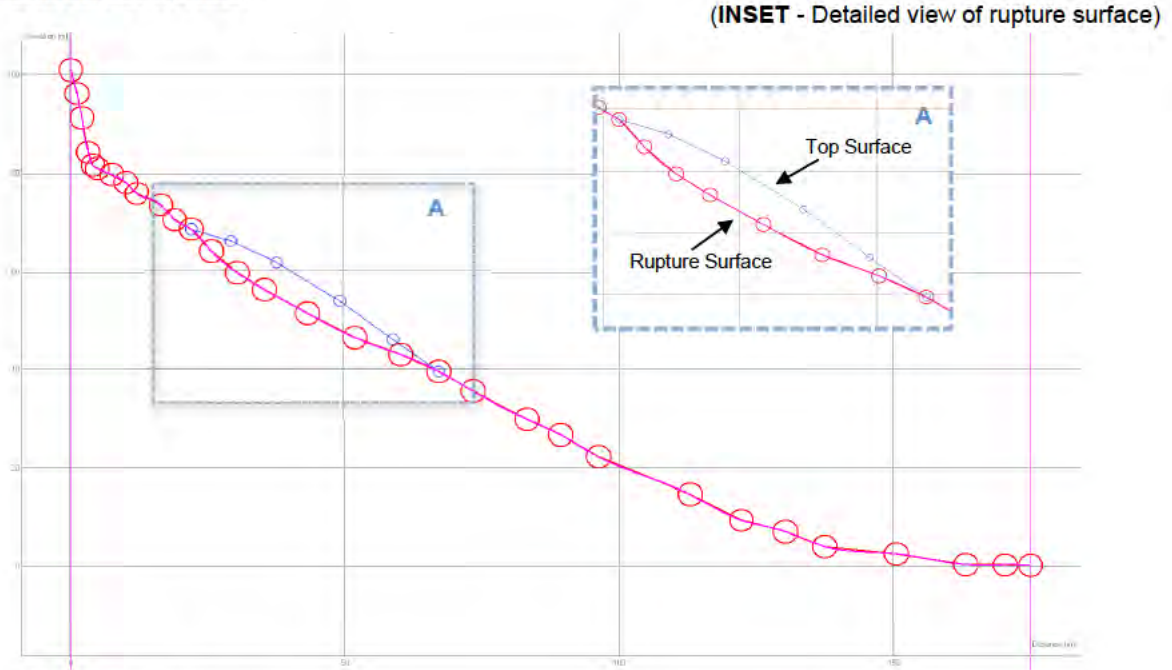


<b>ARUP</b>	<b>JOB TITLE:</b> Christmas Island Debris Flows				
	<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Input Parameters			
<b>Sheet No.:</b> 3	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

3.2 cont' Details of Analysis Results

Landslide ID	A	Estimated Source Volume	2000 m <sup>3</sup>
Hazard Type	OHL	Estimated Entrainment Volume	0 m <sup>3</sup>

**SECTIONAL PROFILE**



**WIDTH PROFILE**



**MATERIAL PROPERTIES**

Chainage (m)	Rheology	Unit Weight (kN/m <sup>3</sup> )	Friction Angle (°)	Pore Pressure Coefficient	Friction Coefficient	Turbulence Coefficient (m/s <sup>2</sup> )	Internal Angle of Friction (°)	Erosion Depth (m)
0-175	Frictional	19	29.5	-	-	-	35	0

**NOTE:** See Section 2.4 for explanation of Material Properties

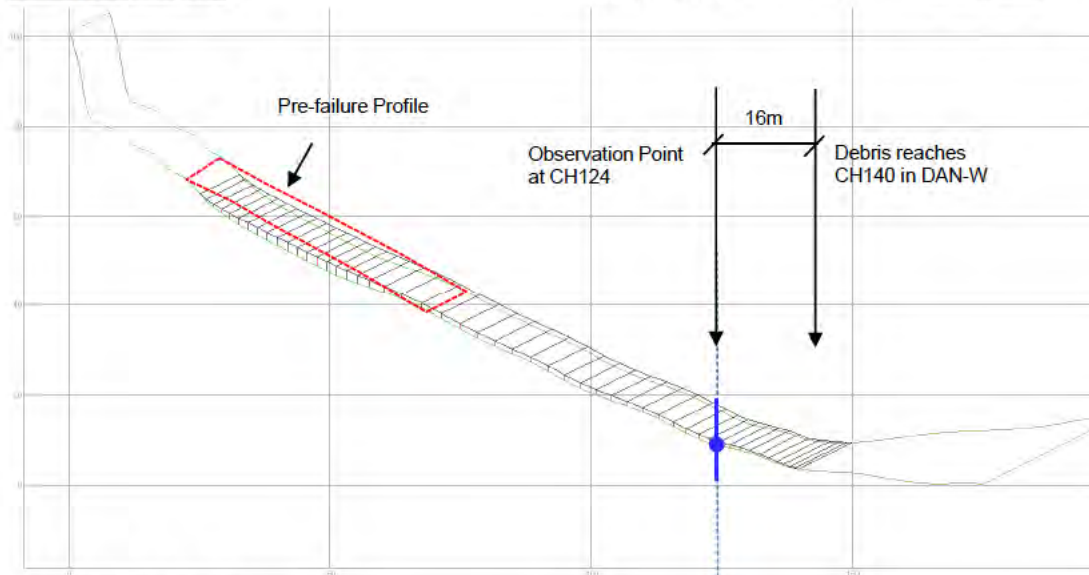
<b>ARUP</b>		<b>JOB TITLE:</b> Christmas Island Debris Flows			
		<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Output Results		
<b>Sheet No.:</b> 4	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

Failure ID: **A**  
 Hazard Type: **OHL**

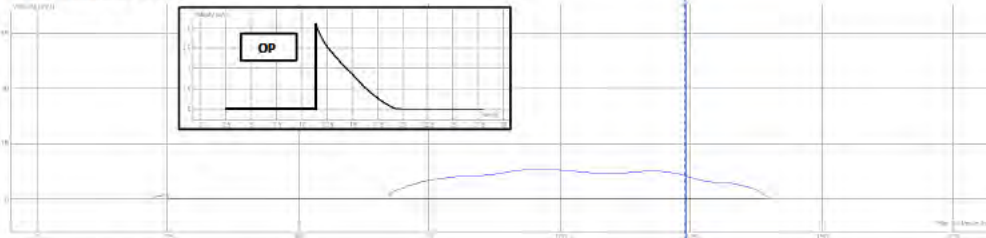
**DEBRIS VOLUME**

Computed Source Volume: **2007.00 m<sup>3</sup>**  
 Computed Entrainment: **0.00 m<sup>3</sup>**

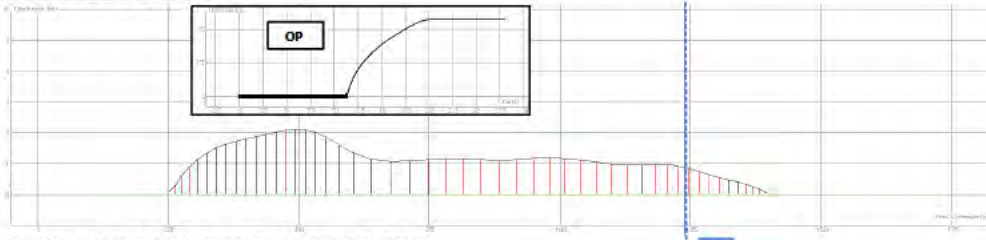
**FAILURE PROFILE**



**VELOCITY PROFILE**



**THICKNESS PROFILE**



**DEBRIS RUN-OUT CHARACTERISTICS**

Total Computed Debris Volume (m <sup>3</sup> )	Run-out	OP
Total Debris Volume passing OP	2007.00	122.8
Maximum Debris Thickness (m)	4.58	0.87
Maximum Debris Velocity (m/s)	8.12	6.24

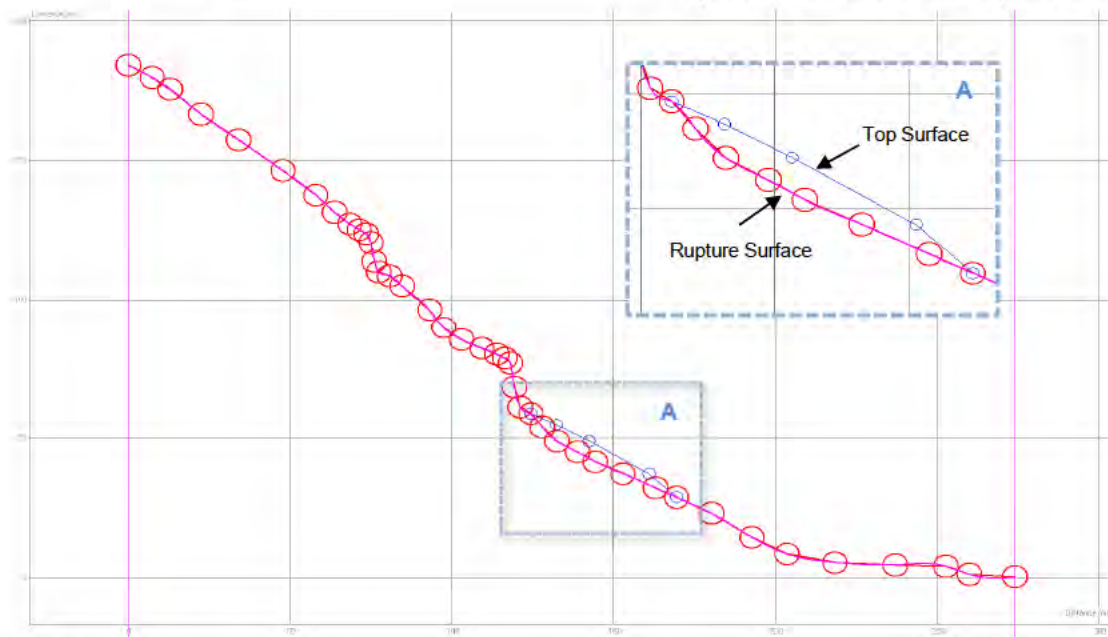
<b>ARUP</b>	<b>JOB TITLE:</b> Christmas Island Debris Flows				
	<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Input Parameters			
<b>Sheet No.:</b> 5	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

3.2 cont' **Details of Analysis Results**

Landslide ID	B	Estimated Source Volume	2000.00 m <sup>3</sup>
Hazard Type	OHL	Estimated Entrainment Volume	0 m <sup>3</sup>

**SECTIONAL PROFILE**

(INSET - Detailed view of rupture surface)



**WIDTH PROFILE**



**MATERIAL PROPERTIES**

Chainage (m)	Rheology	Unit Weight (kN/m <sup>3</sup> )	Friction Angle (°)	Pore Pressure Coefficient	Friction Coefficient	Turbulence Coefficient (m/s <sup>2</sup> )	Internal Angle of Friction (°)	Erosion Depth (m)
0-274	Frictional	19	29.5	-	-	-	35	0

**NOTE:** See Section 2.4 for explanation of Material Properties

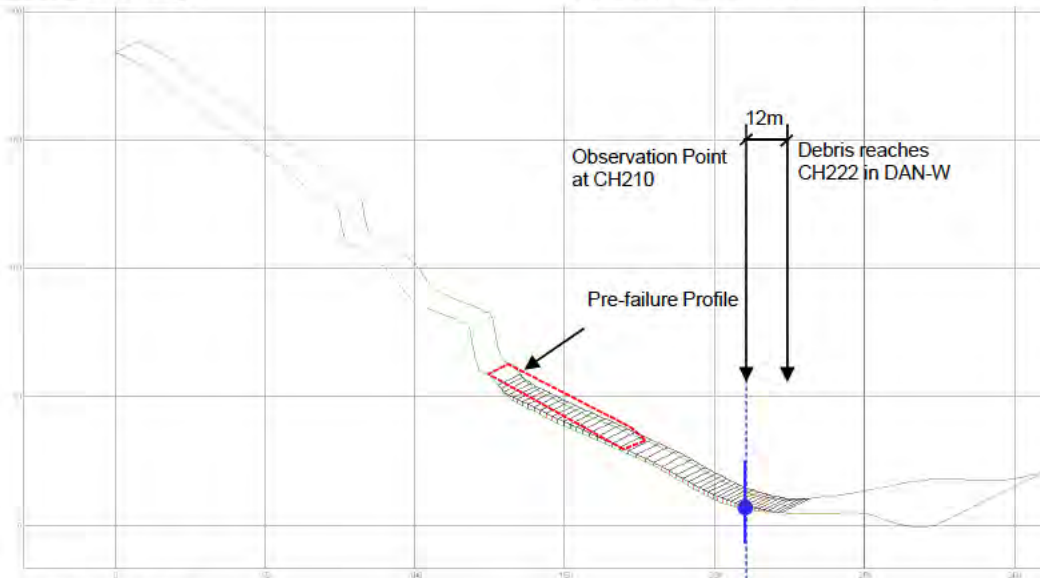
<b>ARUP</b>		<b>JOB TITLE:</b> Christmas Island Debris Flows				
		<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Output Results			
<b>Sheet No.:</b>	6	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

Failure ID: **B**  
 Hazard Type: **OHL**

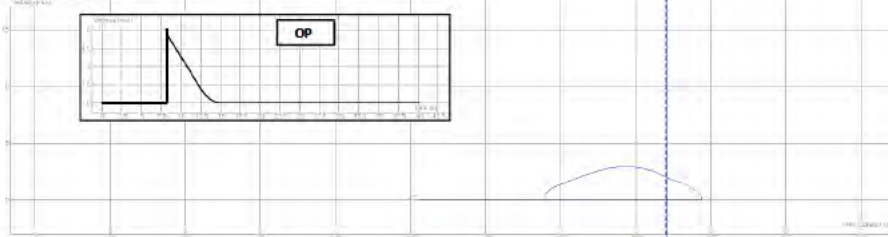
**DEBRIS VOLUME**

Computed Source Volume: 2002.00 m<sup>3</sup>  
 Computed Entrainment: 0.00 m<sup>3</sup>

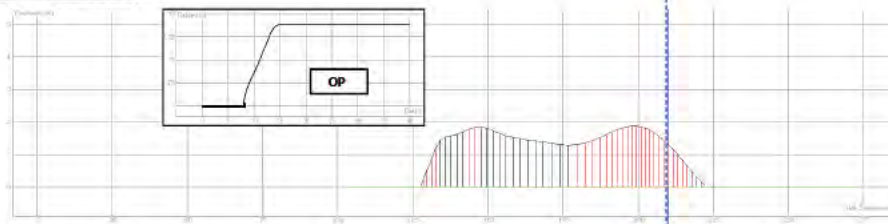
**FAILURE PROFILE**



**VELOCITY PROFILE**



**THICKNESS PROFILE**



**DEBRIS RUN-OUT CHARACTERISTICS**

Total Computed Debris Volume (m <sup>3</sup> )	Run-out	OP
Total Debris Volume passing OP	2002.00	129.9
Maximum Debris Thickness (m)	4.14	1.32
Maximum Debris Velocity (m/s)	8.88	6.1

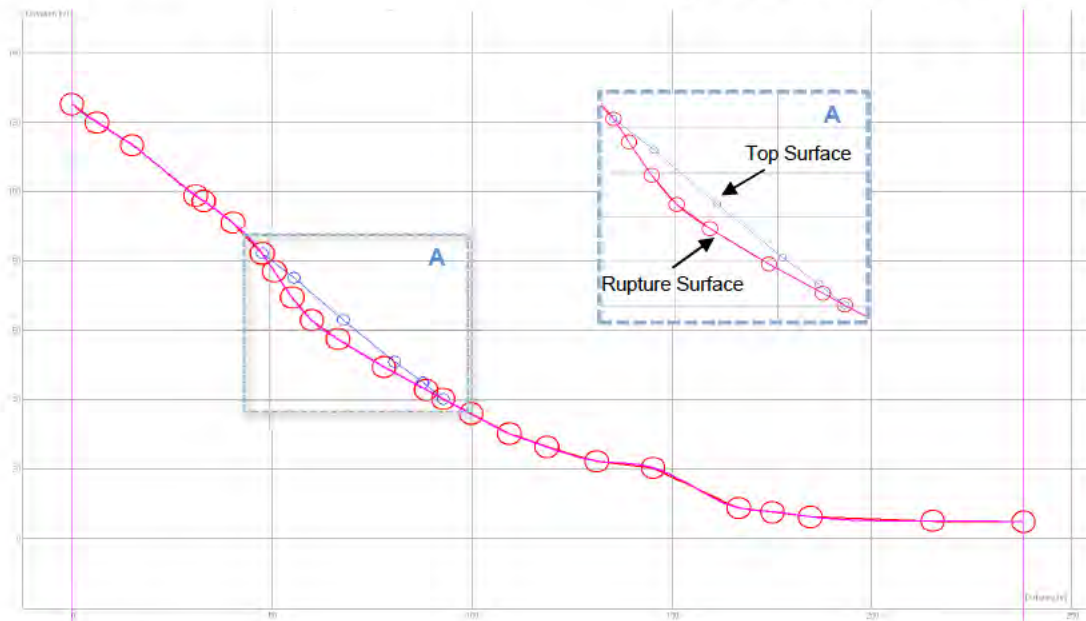
<b>ARUP</b>		<b>JOB TITLE:</b> Christmas Island Debris Flows			
		<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Input Parameters		
<b>Sheet No.:</b> 7	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

3.2 cont' Details of Analysis Results

Landslide ID	E	Estimated Source Volume	2000	m <sup>3</sup>
Hazard Type	OHL	Estimated Entrainment Volume	0	m <sup>3</sup>

**SECTIONAL PROFILE**

(INSET - Detailed view of rupture surface)



**WIDTH PROFILE**



**MATERIAL PROPERTIES**

Chainage (m)	Rheology	Unit Weight (kN/m <sup>3</sup> )	Friction Angle (°)	Pore Pressure Coefficient	Friction Coefficient	Turbulence Coefficient (m/s <sup>2</sup> )	Internal Angle of Friction (°)	Erosion Depth (m)
0-238	Frictional	19	29.5	-	-	-	35	0

**NOTE:** See Section 2.4 for explanation of Material Properties

# ARUP

**JOB TITLE:** Christmas Island Debris Flows

**Sheet No.:** 8

**JOB NUMBER:** 268575 **SHEET DESCRIPTION:** Output Results

**Date:** June 2019 **Drawn:** MS **Checked:** AC **Approved:** JY **Revision:** 0

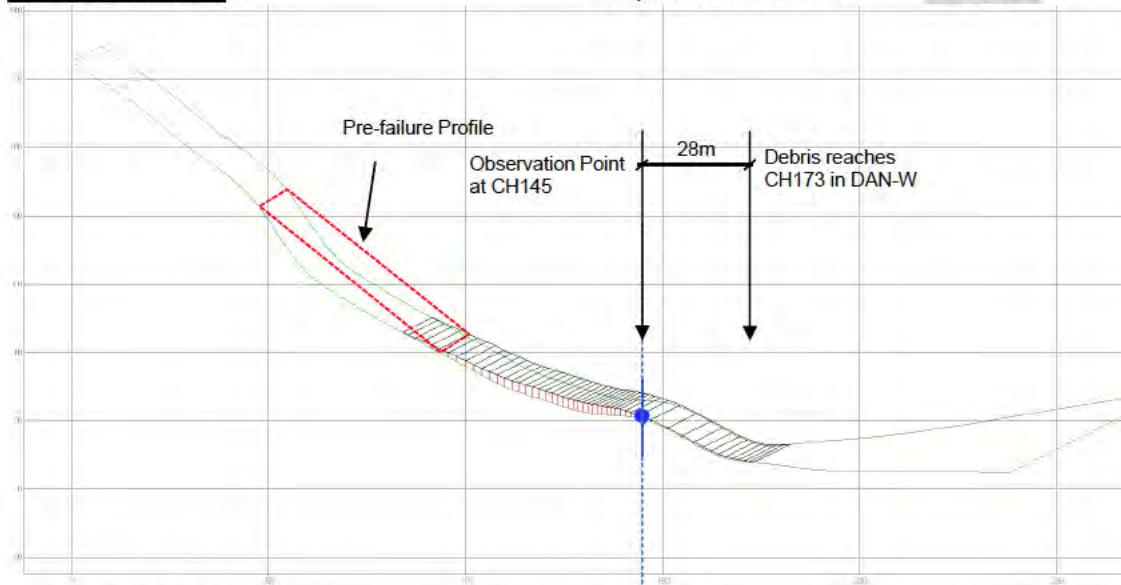
Failure ID  
Hazard Type

E  
OHL

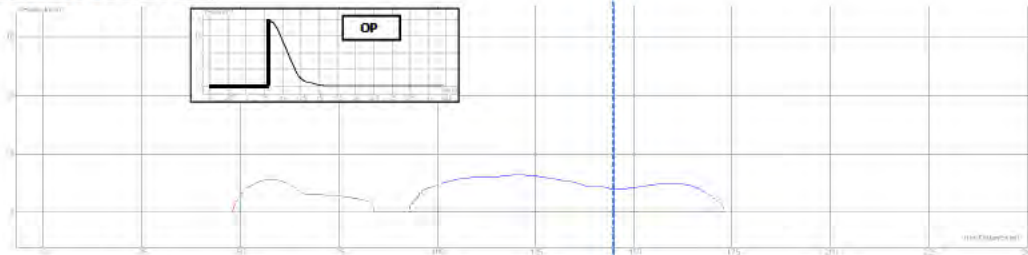
**DEBRIS VOLUME**

Computed Source Volume 2007.00 m<sup>3</sup>  
Computed Entrainment 0.00 m<sup>3</sup>

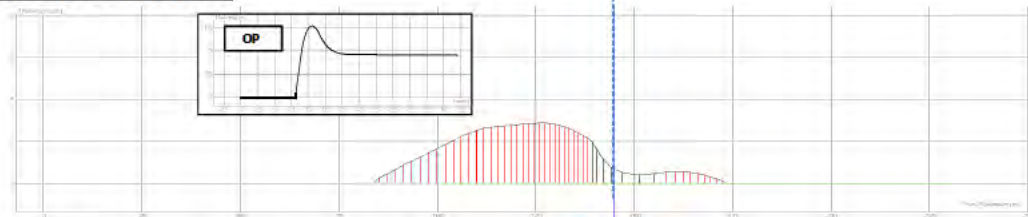
**FAILURE PROFILE**



**VELOCITY PROFILE**



**THICKNESS PROFILE**



**DEBRIS RUN-OUT CHARACTERISTICS**

	Run-out	OP
Total Computed Debris Volume (m <sup>3</sup> )	2007.00	
Total Debris Volume passing OP		194.5
Maximum Debris Thickness (m)	5.28	1.16
Maximum Debris Velocity (m/s)	10.13	6.02

<b>ARUP</b>		<b>JOB TITLE:</b> Christmas Island Debris Flows				
		<b>JOB NUMBER:</b> 268575	<b>SHEET DESCRIPTION:</b> Output Sheet			
<b>Sheet No.:</b>	9	<b>Date:</b> June 2019	<b>Drawn:</b> MS	<b>Checked:</b> AC	<b>Approved:</b> JY	<b>Revision:</b> 0

**ANNEX A**  
**DAN/W Modelling Output Sheets**

## DNW-OUTPUT\_Section A.TXT

DAN-W Release 10

File: G:\Actual Job\268575\11-00 Calculations\02 - DANW\DAN-W Model\DTM  
topo\20190624 2000m3 source volume\SectionA\_29.5deg.DNW

Project: Christmas Island Debris Flow Study  
Data Set: Section A  
Input By: MS  
Date: 6/24/2019

## Vertical slices

## MATERIAL 1:

Name: 1.00  
Rheology: Frictional  
Unit Weight: 19.00  
Friction Angle: 29.50  
Pore Pressure Coeff., Ru: 0.00  
Erosion Depth: 0.00  
Internal Friction Angle: 35.00

No of Blocks = 50  
Time step = 0.001 seconds  
End at time = 35.49 seconds  
Configuration = 3 dimensional  
Boundary Block Geometry = Vertical  
Shape factor = 0.67

## FRONT (final position):

Horiz. Location = 139.82  
Curvilinear Displ.= 81.34  
Horiz. Displ. = 72.52

## REAR (final position):

Horiz. Location= 25.24  
Curvilinear Displ.= 4.52  
Horiz. Displ. = 2.91

## CENTRE OF GRAVITY:

X-Source = 42.11  
Z-Source = 54.43  
X-Depos. = 73.96  
Z-Depos. = 35.96  
CG Ratio = 0.58  
Travel angle = 30.11  
FAHRBOSCHUNG = 28.89

Maximum velocity = 8.12 at X = 95.90  
Maximum front velocity = 8.12 at X = 95.90

## SLIDE VOLUME:

Initial = 2007.39  
Final = 2007.39

## DNW-OUTPUT\_Section A.TXT

## AREA IN PLAN:

Initial = 674.60  
Final = 1734.85

## LENGTH:

Initial = 53.98  
Final = 130.79

## MAXIMUM THICKNESS:

Initial = 4.58  
Final = 2.11

Runout not completed, V-MAX = 0.05

## DNW-OUTPUT\_Section B.TXT

DAN-W Release 10

File: G:\Actual Job\268575\11-00 Calculations\02 - DANW\DAN-W Model\DTM  
topo\20190624 2000m3 source volume\SectionB\_29.5deg.DNW

Project: Christmas Island Debris Flow Study  
Data Set: Section B  
Input By: MS  
Date: 6/24/2019

## Vertical slices

## MATERIAL 1:

Name: 1.00  
Rheology: Frictional  
Unit Weight: 19.00  
Friction Angle: 29.50  
Pore Pressure Coeff., Ru: 0.00  
Erosion Depth: 0.00  
Internal Friction Angle: 35.00

No of Blocks = 50  
Time step = 0.001 seconds  
End at time = 68.35 seconds  
Configuration = 3 dimensional  
Boundary Block Geometry = Vertical  
Shape factor = 0.67

## FRONT (final position):

Horiz. Location = 222.09  
Curvilinear Displ.= 58.51  
Horiz. Displ. = 52.49

## REAR (final position):

Horiz. Location= 127.71  
Curvilinear Displ.= 5.16  
Horiz. Displ. = 3.11

## CENTRE OF GRAVITY:

X-Source = 145.53  
Z-Source = 43.18  
X-Depos. = 173.28  
Z-Depos. = 26.83  
CG Ratio = 0.59  
Travel angle = 30.51  
FAHRBOSCHUNG = 28.82

Maximum velocity = 8.88 at X = 196.94  
Maximum front velocity = 8.88 at X = 196.94

## SLIDE VOLUME:

Initial = 2001.64  
Final = 2001.64

## DNW-OUTPUT\_Section B.TXT

## AREA IN PLAN:

Initial = 675.00  
Final = 1424.11

## LENGTH:

Initial = 54.89  
Final = 108.24

## MAXIMUM THICKNESS:

Initial = 4.14  
Final = 1.87

Runout not completed, V-MAX = 0.01

## DNW-OUTPUT\_Section E.TXT

DAN-W Release 10

File: G:\Actual Job\268575\11-00 Calculations\02 - DANW\ DAN-W Model\DTM  
topo\20190624 2000m3 source volume\SectionE\_29.5deg.DNW

Project: Christmas Island Debris Flow Study  
Data Set: Section E  
Input By: MS  
Date: 6/24/2019

## Vertical slices

## MATERIAL 1:

Name: 1.00  
Rheology: Frictional  
Unit Weight: 19.00  
Friction Angle: 29.50  
Pore Pressure Coeff., Ru: 0.00  
Erosion Depth: 0.00  
Internal Friction Angle: 35.00

No of Blocks = 50  
Time step = 0.001 seconds  
End at time = 22.48 seconds  
Configuration = 3 dimensional  
Boundary Block Geometry = Vertical  
Shape factor = 0.67

## FRONT (final position):

Horiz. Location = 173.16  
Curvilinear Displ.= 87.68  
Horiz. Displ. = 80.16

## REAR (final position):

Horiz. Location= 84.01  
Curvilinear Displ.= 52.07  
Horiz. Displ. = 36.01

## CENTRE OF GRAVITY:

X-Source = 66.96  
Z-Source = 60.43  
X-Depos. = 121.98  
Z-Depos. = 27.49  
CG Ratio = 0.60  
Travel angle = 30.90  
FAHRBOSCHUNG = 30.66

Maximum velocity = 10.13 at X = 105.23  
Maximum front velocity = 9.59 at X = 120.84

## SLIDE VOLUME:

Initial = 2007.11  
Final = 2007.11

## DNW-OUTPUT\_Section E.TXT

## AREA IN PLAN:

Initial = 675.00  
Final = 1342.62

## LENGTH:

Initial = 62.34  
Final = 97.95

## MAXIMUM THICKNESS:

Initial = 5.28  
Final = 2.89

Runout not completed, V-MAX = 0.09

## C4 Rock Fall Analysis

---

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Infrastructure, Transport, Regional Development, Communications, Sport and the Arts



**CALCULATION SHEET -  
RocFall ANALYSIS**

<b>JOB TITLE</b>	Flying Fish Cove, Christmas Island Slope Stability	
<b>JOB NUMBER</b>	268575	
<b>REPORT TITLE</b>	Rock Fall Assessment	<b>Initial</b>
<b>CALCULATED BY</b>	Mike Sham	MS
<b>CHECKED BY</b>	Arthur Cheung	AC
<b>APPROVED BY</b>	Jack Yiu	JY
<b>DATE</b>	June 2019	

**CONTENTS OF SPREADSHEET**

Section	Description	Sheet No.
<b>1.0</b>	<b>INTRODUCTION</b>	1
<b>2.0</b>	<b>METHOD OF ANALYSIS</b>	1
2.1	RocFall Software	1
2.2	Assumptions for RocFall Software	2
2.3	Maximum Values/Data Collectors	2
<b>3.0</b>	<b>ROCFALL ANALYSIS</b>	3
3.1	Summary of Input Parameters	3
3.2	Details of RocFall Analysis Along Section Line	4 to 7
<b>4.0</b>	<b>SUMMARY OF ROCFALL ANALYSIS</b>	8
4.1	Summary of Results	8
<b>5.0</b>	<b>CONCLUSIONS</b>	9

**REVISIONS**      Current Revision:

Rev.	Date	Calculated by	Checked by	Description
0	24/06/19	MS	AC	Draft Submission

<b>ARUP</b>		<b>JOB TITLE:</b>		Flying Fish Cove, Christmas Island Slope Stability	
		<b>JOB NUMBER:</b>		268575	<b>SHEET DESCRIPTION:</b>
<b>Sheet No.:</b>	1			Introduction and Methodology for RocFall Analysis	
<b>Date:</b>	June 2019	<b>Prepared by:</b>	MS	<b>Checked by:</b>	AC
				<b>Approved by:</b>	JY
				<b>Revision:</b>	0

**1.0 INTRODUCTION**

The potential rock/boulder fall movements within critical catchment areas were analyzed based on the findings of the field inspections of the sites.

**2.0 METHOD OF ANALYSES**

**2.1 RocFall Software**

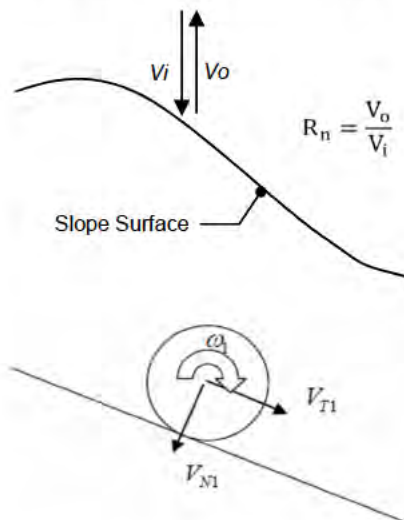
The computer programme RocFall Version 4.052 (Year 2010) has been used for the probabilistic simulation and statistical analysis of potential rock/boulder fall. Analysis of rock/boulder fall has been carried out based on the critical slope geometry, friction angles and material properties (coefficients of restitution) of the sliding surface identified from the field inspections. The maximum travel distance of rocks, total kinetic energy, translational velocity and bouncing height of the potential rock/boulder have been measured and plotted against the distance from the source. The results have then used to determine appropriate mitigation strategies.

The material coefficients, the coefficient of normal restitution ( $R_n$ ) and coefficient of tangential restitution ( $R_t$ ) are illustrated below and were determined with due reference to the Rocscience Coefficient of Restitution Table. The material coefficients used for the analysis are summarised as follows:

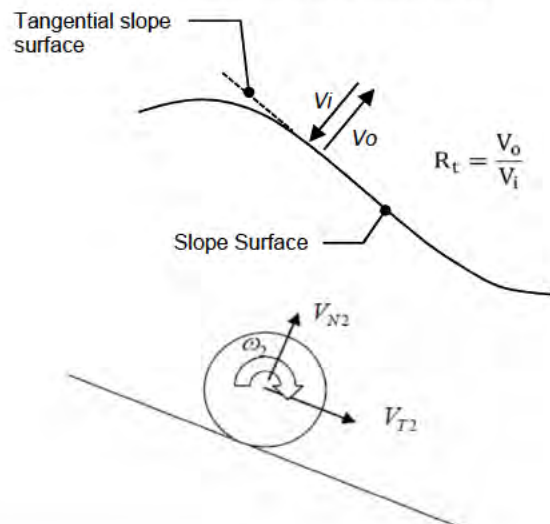
Materials	$R_n$	$R_t$
Asphalt	0.4	0.9
Bedrock outcrops	0.35	0.85
Talus cover	0.32	0.82

Rock Type	Rock Density ( $kg/m^3$ )
Medium sized rock	2800

**Coefficient of Normal Restitution ( $R_n$ ):**



**Coefficient of Tangential Restitution ( $R_t$ ):**



$V_i$	Incoming Velocity
$V_o$	Outgoing Velocity

<b>ARUP</b>		<b>JOB TITLE:</b>	Flying Fish Cove, Christmas Island Slope Stability						
		<b>JOB NUMBER:</b>	268575	<b>SHEET DESCRIPTION:</b>	Introduction and Methodology for RocFall Analysis				
<b>Sheet No.:</b>	2	<b>Prepared by:</b>	MS	<b>Checked by:</b>	AC	<b>Approved by:</b>	JY	<b>Revision:</b>	0
<b>Date:</b>	June 2019								

**2.2 Assumptions for RocFall Analysis**

- Each rock/boulder is modelled as a particle.
- The particle is an infinitesimal circle.
- There is no interaction between particles, only with slope segments and barriers.
- The mass of the particle is determined at the beginning of the stimulation and stays constant throughout the simulation. That is the rock cannot split into multiple pieces during the simulation.
- The friction angle of the slope segment is assumed to be 30°.
- 1000 iterations are carried out for each analysis for a reasonable result based on probability.
- Rock/boulder fall initiation point was input using the 'line seeder' function in order to indicate rock/boulder falls within those zones / clusters identified as having potential for instability.

**2.3 Maximum Values/Data Collectors**

For each analysis the following values will be indicated along the trajectory of the rocks/boulders:

- Global Maximum
- Data Collector at the rockfall barrier (DC1) Maximum

Global maximum value indicates the overall highest value for a given output parameter.

A "data collector" is a line segment that gathers information about the rocks/boulders that pass through the data collector while the rocks/boulders are being thrown down the slope. "Data collectors" record the velocity, kinetic energy and bounce height of all rocks/boulders that pass through the data collector as they travel down the slope. Data collectors can be added onto the slope profile to determine such information at specified locations without altering the rock/boulder fall trajectory down slope.

There is no restriction on the number of data collectors or where they can be placed. Data collectors are optional and can be added to RocFall analysis to indicate the rock/boulder fall data at the rockfall barrier for reference purpose.

<b>ARUP</b>		<b>JOB TITLE:</b>		Flying Fish Cove, Christmas Island Slope Stability					
		<b>JOB NUMBER:</b>		268575	<b>SHEET DESCRIPTION:</b>				
<b>Sheet No.:</b>	3			Input Parameters for RocFall Analysis					
<b>Date:</b>	June 2019	<b>Prepared by:</b>	MS	<b>Checked by:</b>	AC	<b>Approved by:</b>	JY	<b>Revision:</b>	0

**3.0 RocFall ANALYSIS**

**3.1 Summary of Input Parameters**

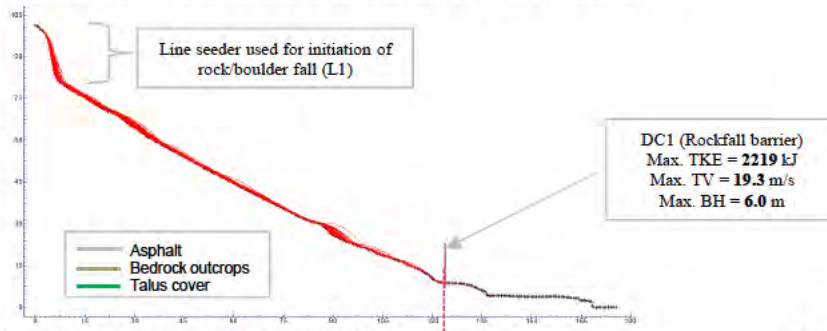
Hazard Type/ID	Section	Section A	Section B - High Cliff	Section B - Low Cliff	Section E
	Section ID	A	B	B	E
	Seeder Type	Line	Line	Line	Line
	Failure ID	A-L1	B-L1	B-L2	E-L1
Rock/Boulder & Slope Geometry	Estimated Rock/Boulder size (m <sup>2</sup> )	3.57	3.57	3.57	3.57
	Estimated Rock/Boulder mass (kg)	10,000	10,000	10,000	10,000

<b>ARUP</b>		<b>JOB TITLE:</b>	Flying Fish Cove, Christmas Island Slope Stability		
<b>Sheet No.:</b>	4	<b>JOB NUMBER:</b>	268575	<b>SHEET DESCRIPTION:</b>	Detailed RocFall Analysis
<b>Date:</b>	June 2019	<b>Prepared by:</b>	MS	<b>Checked by:</b>	AC
				<b>Approved by:</b>	JY
				<b>Revision:</b>	0

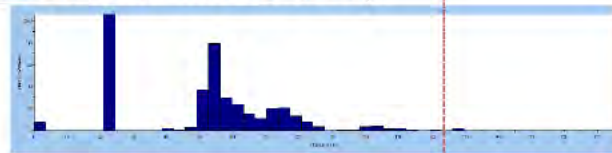
### 3.2 Details of RocFall Analysis Along Section Line

Section: Section A  
 Section ID: A  
 Failure ID: A-L1  
 Estimated Boulder Size: 3.57 m<sup>3</sup>

#### SLOPE PROFILE AND TRAJECTORY OF ROCK/BOULDER

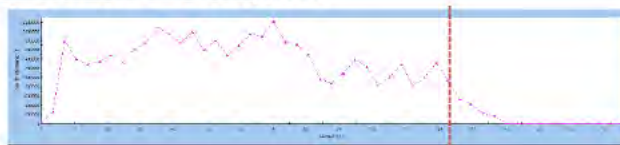


#### HORIZONTAL LOCATION OF ROCK



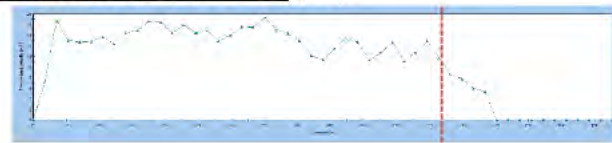
Global  
 Max.: 139 m

#### TOTAL KINETIC ENERGY (TKE)



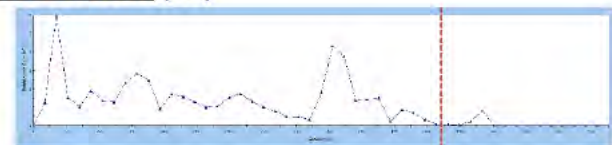
Global DC1  
 Max.: 2,219 938 kJ

#### TRANSLATIONAL VELOCITY (TV)



Global DC1  
 Max.: 19.3 11.8 m/s

#### BOUNCE HEIGHT (BH)



Global DC1  
 Max.: 6.0 0.1 m

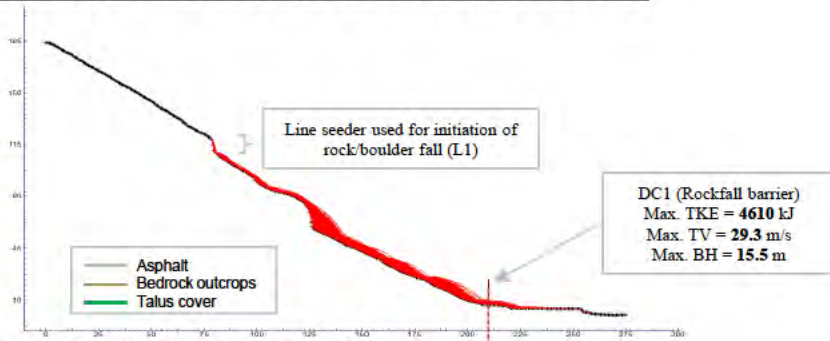
DC1

<b>ARUP</b>		<b>JOB TITLE:</b>	Flying Fish Cove, Christmas Island Slope Stability		
<b>Sheet No.:</b>	5	<b>JOB NUMBER:</b>	268575	<b>SHEET DESCRIPTION:</b>	Detailed RocFall Analysis
<b>Date:</b>	June 2019	<b>Prepared by:</b>	MS	<b>Checked by:</b>	AC
				<b>Approved by:</b>	JY
				<b>Revision:</b>	0

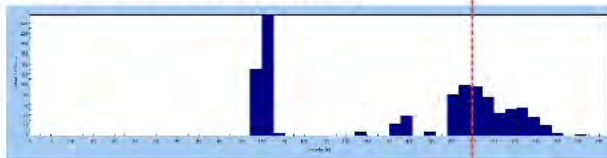
**3.2 Details of RocFall Analysis Along Section Line**

Section: Section B - High Cliff      Failure ID: B-L1  
 Section ID: B      Estimated Boulder Size: 3.57 m<sup>3</sup>

**SLOPE PROFILE AND TRAJECTORY OF ROCK/BOULDER**

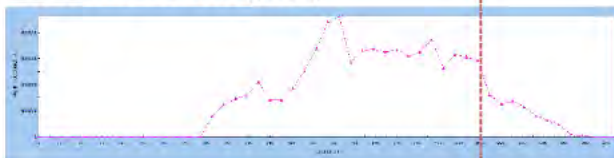


**HORIZONTAL LOCATION OF ROCK**



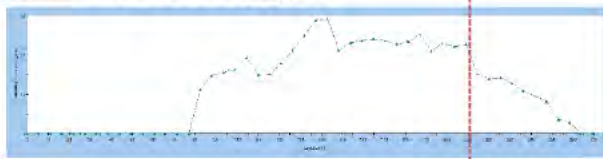
Max.: Global 261 m

**TOTAL KINETIC ENERGY (TKE)**



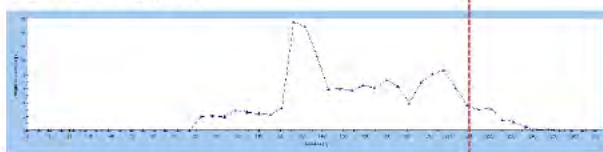
Max.: Global 4,610 DC1 2,932 kJ

**TRANSLATIONAL VELOCITY (TV)**



Max.: Global 29.3 DC1 22.7 m/s

**BOUNCE HEIGHT (BH)**



Max.: Global 15.5 DC1 3.6 m

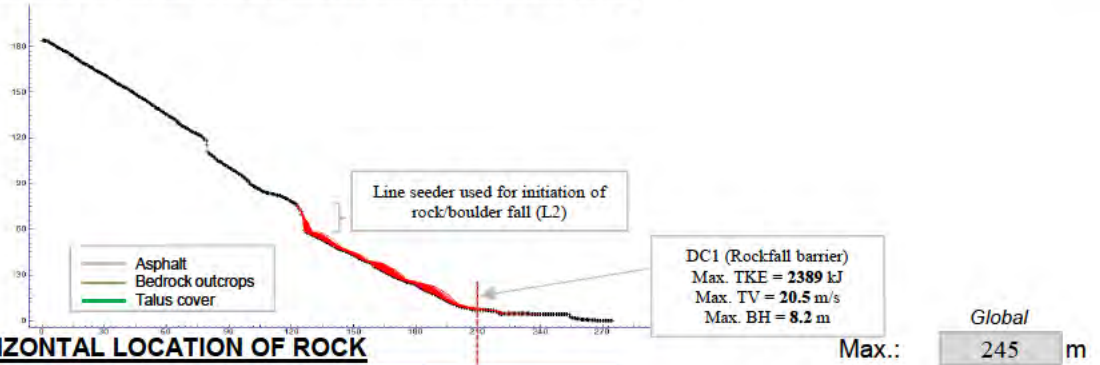
DC1

<b>ARUP</b>		<b>JOB TITLE:</b>	Flying Fish Cove, Christmas Island Slope Stability		
<b>Sheet No.:</b>	6	<b>JOB NUMBER:</b>	268575	<b>SHEET DESCRIPTION:</b>	Detailed RocFall Analysis
<b>Date:</b>	June 2019	<b>Prepared by:</b>	MS	<b>Checked by:</b>	AC
				<b>Approved by:</b>	JY
				<b>Revision:</b>	0

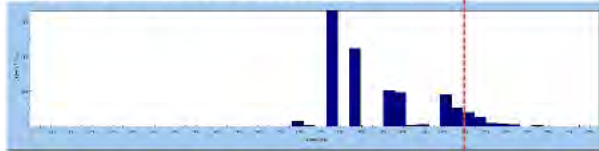
3.2 Details of RocFall Analysis Along Section Line

Section: Section B - Low Cliff  
 Section ID: B  
 Failure ID: B-L2  
 Estimated Boulder Size: 3.57 m<sup>3</sup>

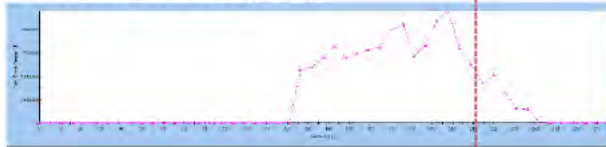
**SLOPE PROFILE AND TRAJECTORY OF ROCK/BOULDER**



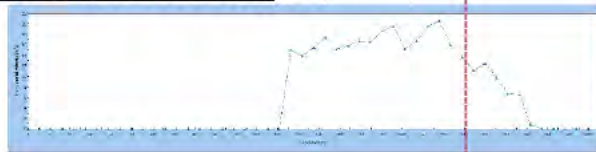
**HORIZONTAL LOCATION OF ROCK**



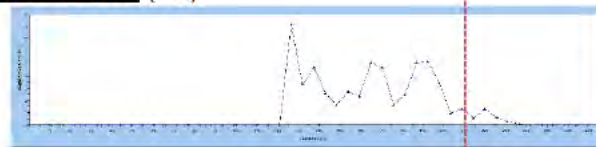
**TOTAL KINETIC ENERGY (TKE)**



**TRANSLATIONAL VELOCITY (TV)**



**BOUNCE HEIGHT (BH)**



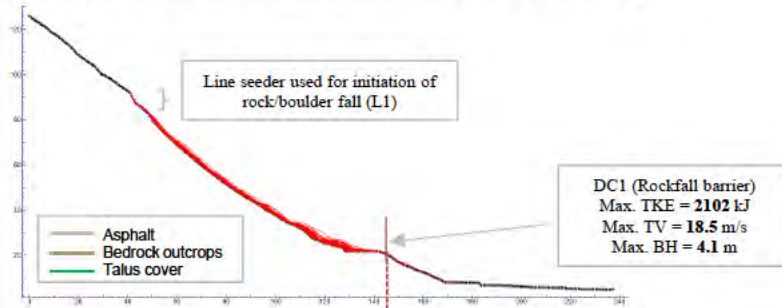
DC1

<b>ARUP</b>		<b>JOB TITLE:</b>	Flying Fish Cove, Christmas Island Slope Stability		
<b>Sheet No.:</b>	7	<b>JOB NUMBER:</b>	268575	<b>SHEET DESCRIPTION:</b>	Detailed RocFall Analysis
<b>Date:</b>	June 2019	<b>Prepared by:</b>	MS	<b>Checked by:</b>	AC
				<b>Approved by:</b>	JY
				<b>Revision:</b>	0

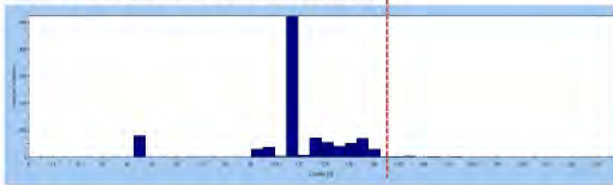
**3.2 Details of RocFall Analysis Along Section Line**

Section: Section E Failure ID: E-L1  
 Section ID: E Estimated Boulder Size: 3.57 m<sup>3</sup>

**SLOPE PROFILE AND TRAJECTORY OF ROCK/BOULDER**

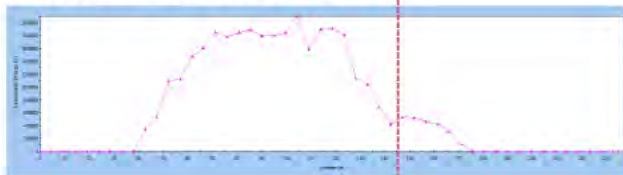


**HORIZONTAL LOCATION OF ROCK**



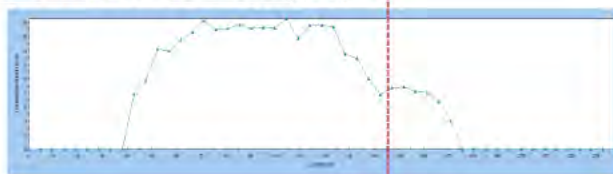
Max.: Global 174 m

**TOTAL KINETIC ENERGY (TKE)**



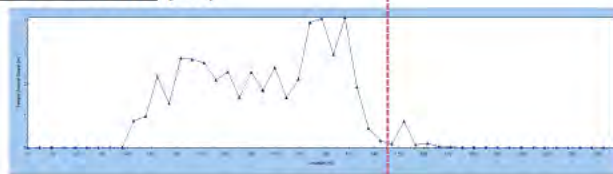
Max.: Global 2,102 DC1 527 kJ

**TRANSLATIONAL VELOCITY (TV)**



Max.: Global 18.5 DC1 8.7 m/s

**BOUNCE HEIGHT (BH)**



Max.: Global 4.1 DC1 0.2 m

DC1

<b>ARUP</b>		<b>JOB TITLE:</b>		Flying Fish Cove, Christmas Island Slope Stability	
		<b>JOB NUMBER:</b>		268575	<b>SHEET DESCRIPTION:</b>
<b>Sheet No.:</b>	8			Results of RocFall Analysis	
<b>Date:</b>	June 2019	<b>Prepared by:</b>	MS	<b>Checked by:</b>	AC
				<b>Approved by:</b>	JY
				<b>Revision:</b>	0

**4.0 SUMMARY OF ROCKFALL ANALYSIS**

**4.1 Summary of Results**

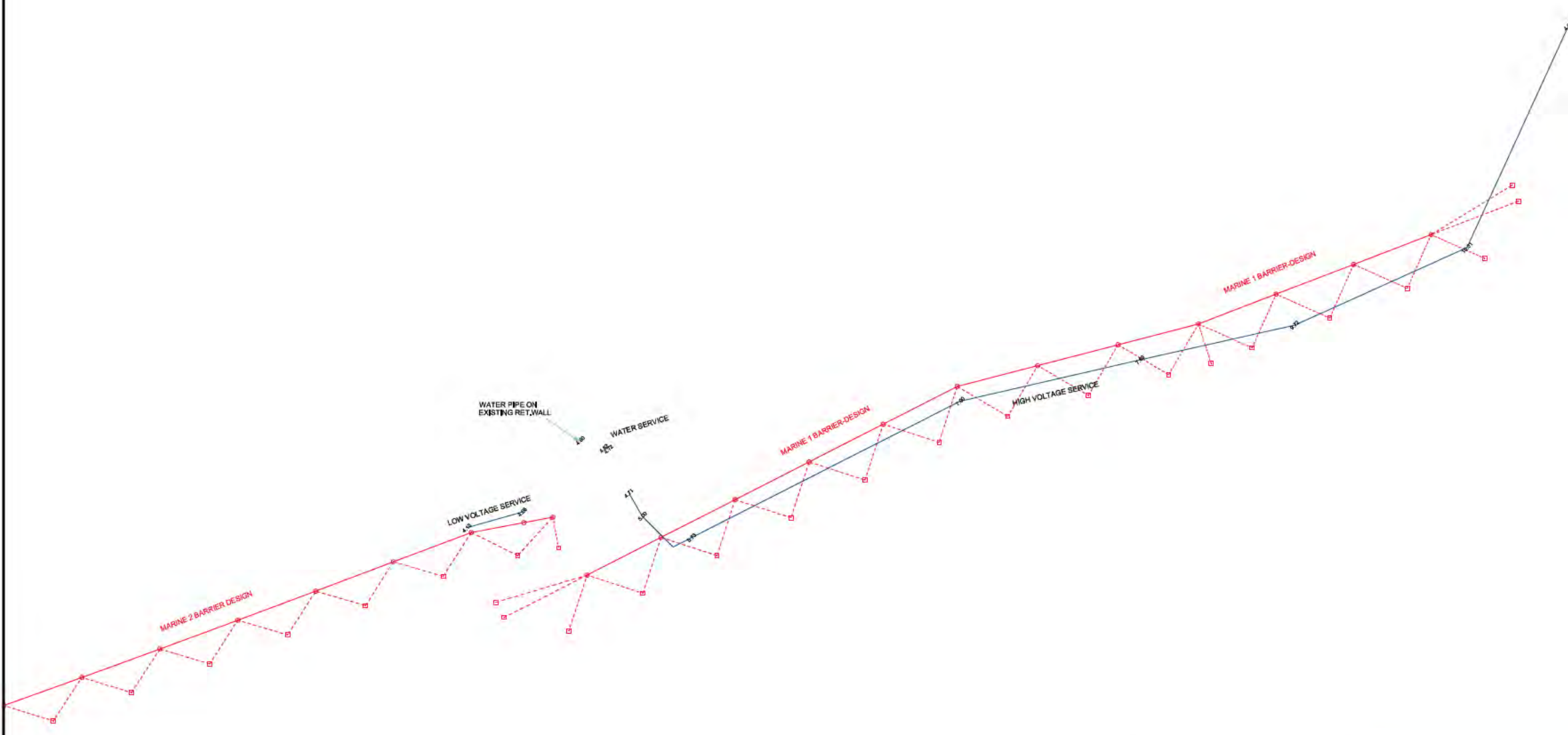
Hazard Type/ID	Section	Section A	Section B - High Cliff	Section B - Low Cliff	Section E
	Section ID	A	B	B	E
	Seeder Type	Line	Line	Line	Line
	Failure ID	A-L1	B-L1	B-L2	E-L1
Global Maximums	Travel Distance from Source (m)	139	261	245	174
	Total Kinetic Energy (kJ)	2,219	4,610	2,389	2,102
	Translational Velocity (m/s)	19.3	29.3	20.5	18.5
	Bounce Height (m)	6.0	15.5	8.2	4.1
Data Collector 1 (Rockfall Barrier) Maximums	Max. Total Kinetic Energy (kJ)	938	2,932	1,266	527
	Max. Translational Velocity (m/s)	11.8	22.7	13.7	8.7
	Max. Bounce Height (m)	0.1	3.6	1.3	0.2
Rock(s) Reaching Barrier		Yes	Yes	Yes	Yes

<b>ARUP</b>		<b>JOB TITLE:</b>		Flying Fish Cove, Christmas Island Slope Stability				
		<b>JOB NUMBER:</b>		268575	<b>SHEET DESCRIPTION:</b>	Results of RocFall Analysis		
<b>Sheet No.:</b>	9	<b>Date:</b>		June 2019	<b>Prepared by:</b> MS	<b>Checked by:</b> AC	<b>Approved by:</b> JY	<b>Revision:</b> 0

## 5.0 Conclusion

Based on the RocFall analysis, the rockfall barrier at the toe of the cliff is likely to be affected by rock/boulder fall hazards. Therefore, mitigation measures for rock/boulder fall hazard are required based on the analysis.

The analysis shows that the maximum bounce height at the rockfall barrier is about 3.6m and the maximum kinetic energy at the barrier is about 2932kJ. To address the rock/boulder fall hazards, it is therefore suggested that a 5000kJ barrier with at least 5m high shall be sufficient.



Scales  
**N.T.S**  
Design Model Version  
Do not scale

Issue	Date	By	Chkd	Appd

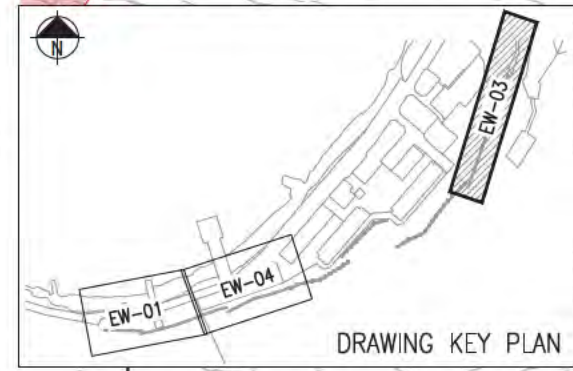
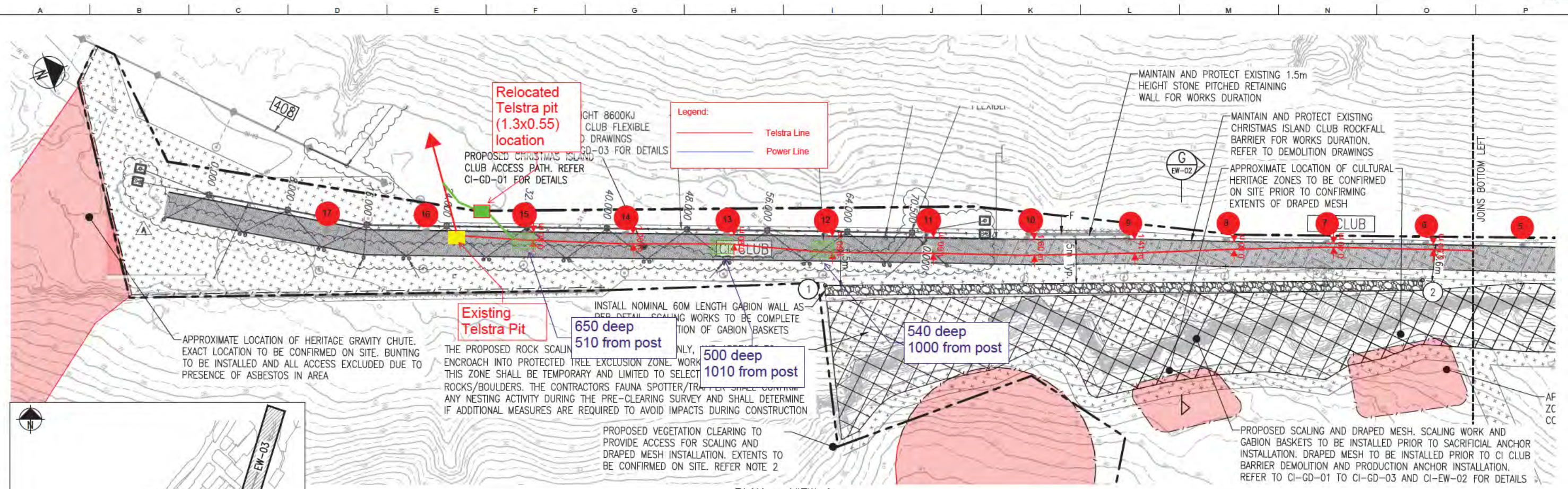
Australian Government  
Department of Infrastructure, Transport,  
Regional Development and Communications

Client  
**AUSTRALIAN GOVERNMENT DPT  
OF INFRASTRUCTURE, TRANSPORT,  
REGIONAL DEVELOPMENT  
AND COMMUNICATIONS**  
Engineering Certification (Comp)  
Name: \_\_\_\_\_ Date: \_\_\_\_\_  
Signature: \_\_\_\_\_

**Dimensions in .dwg**

Drawing Title	
Landslide Mitigation Location of HV @ Marine 1	
Issue	AC

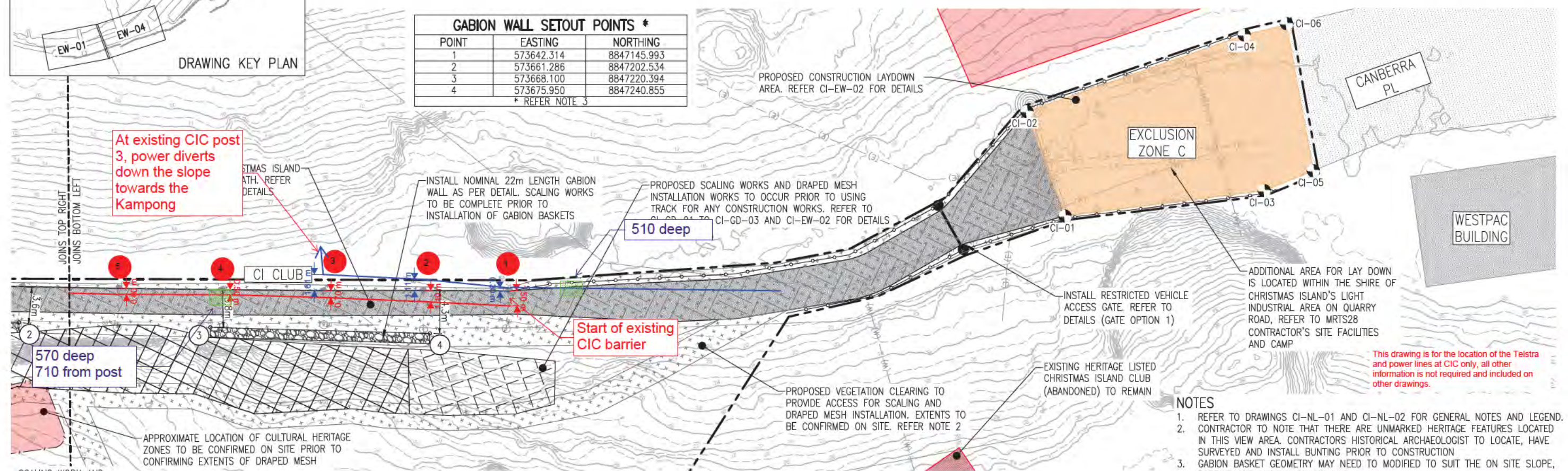
**DRAWING COLOUR CODED - PRINT ALL COPIES IN COLOUR**



**GABION WALL SETOUT POINTS \***

POINT	EASTING	NORTHING
1	573642.314	8847145.993
2	573661.286	8847202.534
3	573668.100	8847220.394
4	573675.950	8847240.855

\* REFER NOTE 3



- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - CONTRACTOR TO NOTE THAT THERE ARE UNMARKED HERITAGE FEATURES LOCATED IN THIS VIEW AREA. CONTRACTORS HISTORICAL ARCHAEOLOGIST TO LOCATE, HAVE SURVEYED AND INSTALL BUNTING PRIOR TO CONSTRUCTION
  - GABION BASKET GEOMETRY MAY NEED TO MODIFIED TO SUIT THE ON SITE SLOPE, BARRIER AND VEGETATION EXTENTS.

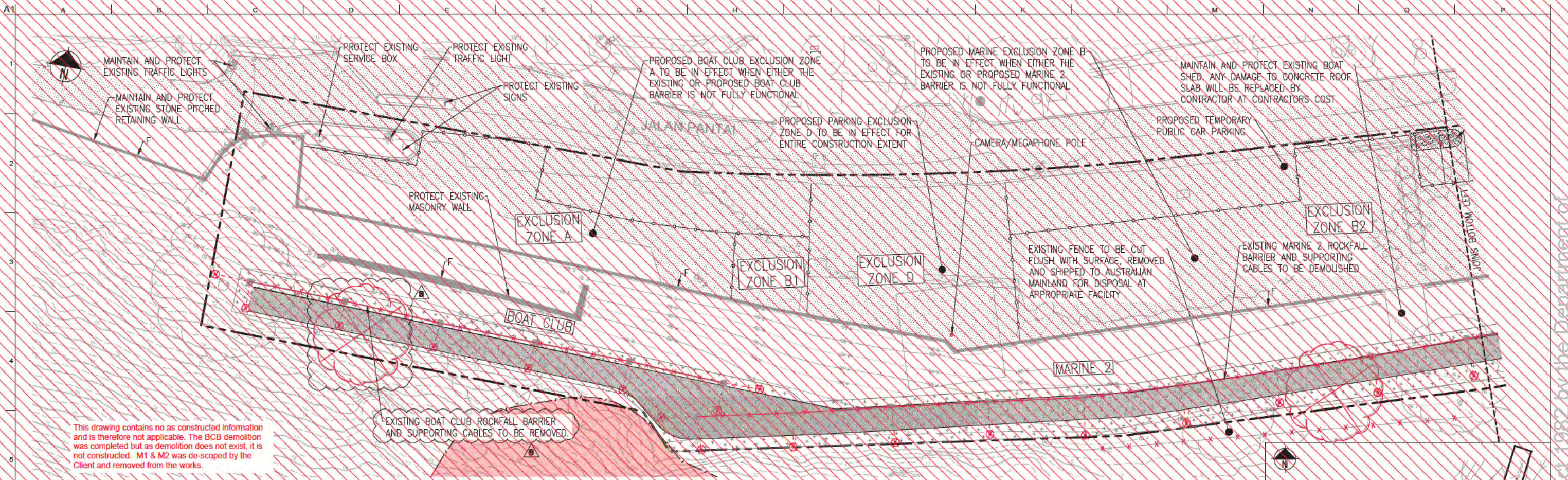
**ISSUED FOR CONSTRUCTION**

<p>Scales</p> <p>A1 / A3 1:200 / 1:400</p> <p>0 2 4 6 8m</p> <p>Design Model Version</p>	<table border="1"> <tr> <td>Issue</td> <td>Date</td> <td>By</td> <td>Child</td> <td>Appd</td> </tr> <tr> <td> </td> <td> </td> <td> </td> <td> </td> <td> </td> </tr> </table>	Issue	Date	By	Child	Appd						<table border="1"> <tr> <td>Issue</td> <td>Date</td> <td>By</td> <td>Child</td> <td>Appd</td> </tr> <tr> <td>A</td> <td>04/08/20</td> <td>RB</td> <td>JG</td> <td>EF</td> </tr> </table> <p>ISSUED FOR CONSTRUCTION</p>	Issue	Date	By	Child	Appd	A	04/08/20	RB	JG	EF	<p>Australian Government Department of Infrastructure, Transport, Regional Development and Communications</p>	<p>Client AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS</p> <p>Engineering Certification (CEng) Name: _____ Date: _____ Signature: _____</p>	<p>Job Title FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN</p> <p>Scale at A1: 1:200</p> <p>Discipline</p>	<p><b>ARUP</b></p> <p>Level 4 108 Wickham Street Fortitude Valley QLD Australia 4006 Tel: +61 (0)7 320 9320 Fax: +61 (0)7 320 9321 www.arup.com</p> <p>Member Firm Aus Pty Ltd ABN 18 000 960 165</p>	<p>Drawing Title LANDSLIDE MITIGATION ACCESS PATH DETAILS SHEET 2</p> <p>Drawing Status <b>ISSUED FOR CONSTRUCTION</b></p> <p>Job No 268575-00</p> <p>Drawing No CHEW-03</p> <p>Issue A</p>
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A	04/08/20	RB	JG	EF																							

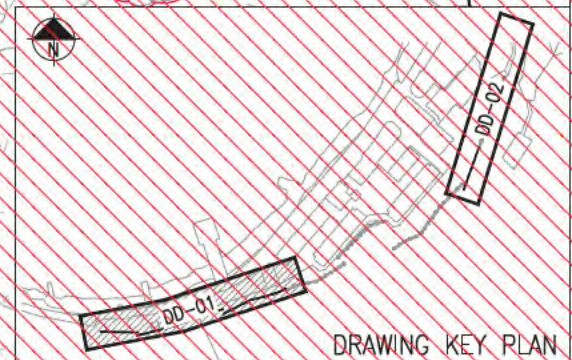
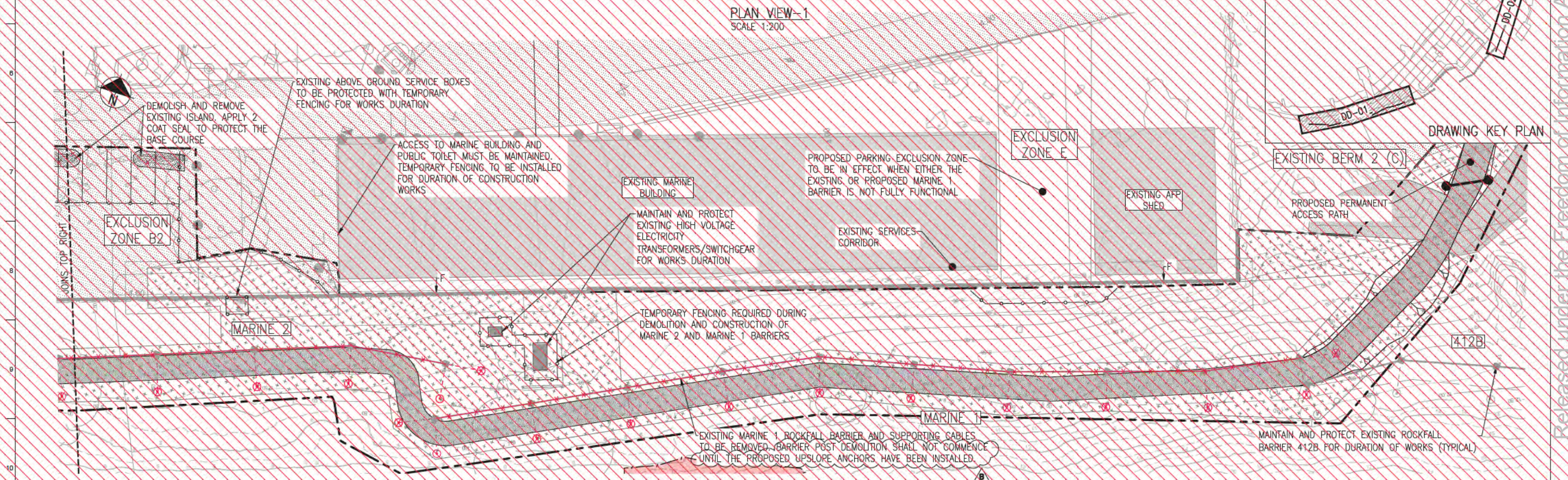
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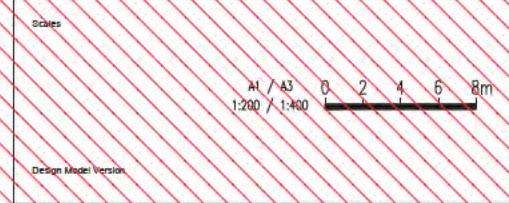


This drawing contains no as constructed information and is therefore not applicable. The BCB demolition was completed but as demolition does not exist, it is not constructed. M1 & M2 was de-scoped by the Client and removed from the works.



NOTES  
1. REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.

**ISSUED FOR CONSTRUCTION**



Issue	Date	By	Check	Appr.
B	24/08/20	RB	JG	EF
Revised IFC				
A	04/08/20	RB	JG	EF
ISSUED FOR CONSTRUCTION				

Australian Government  
Department of Infrastructure, Transport,  
Regional Development and Communications

Client  
**AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS**

Job Title  
**FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN**

**ARUP**  
Level 4, 108 Wickham Street  
Fitzroy, Victoria, Australia 3068  
Tel: +61 (0)3 920 3200 Fax: +61 (0)3 920 3321  
www.arup.com

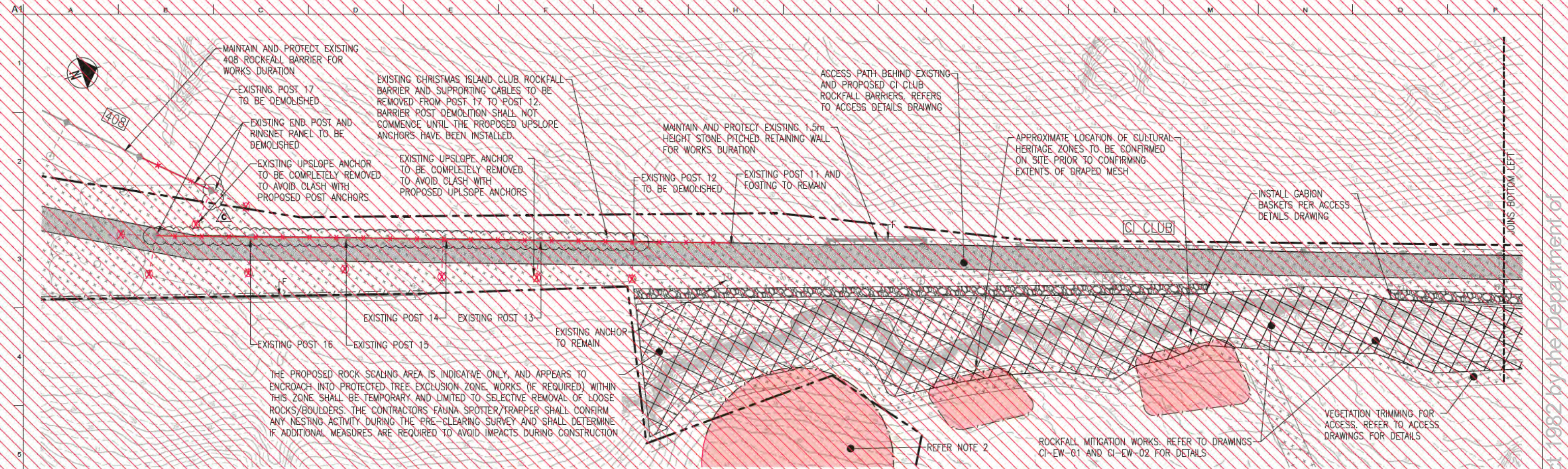
Drawing Title  
**LANDSLIDE MITIGATION BOATCLUB, MARINE 1 & MARINE 2 DEMOLITION PLAN**

Drawing Status  
**ISSUED FOR CONSTRUCTION**

Job No  
**268575-00**

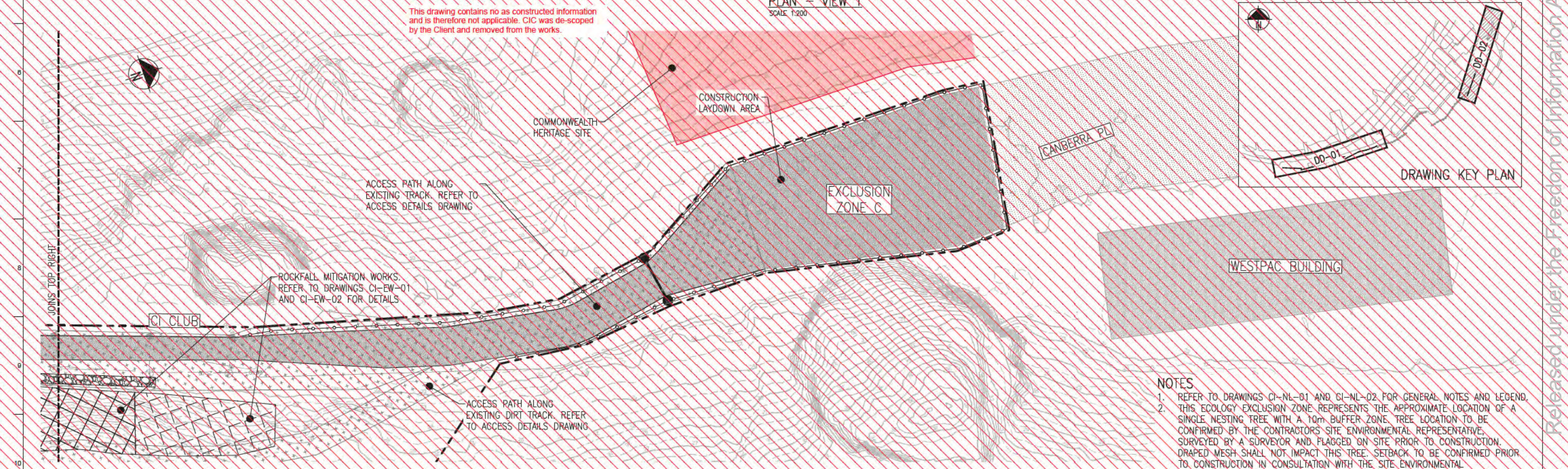
Drawing No  
**C-DD-01**

Issue  
**B**



PLAN - VIEW 1  
SCALE 1:200

This drawing contains no as constructed information and is therefore not applicable. CIC was de-scoped by the Client and removed from the works.



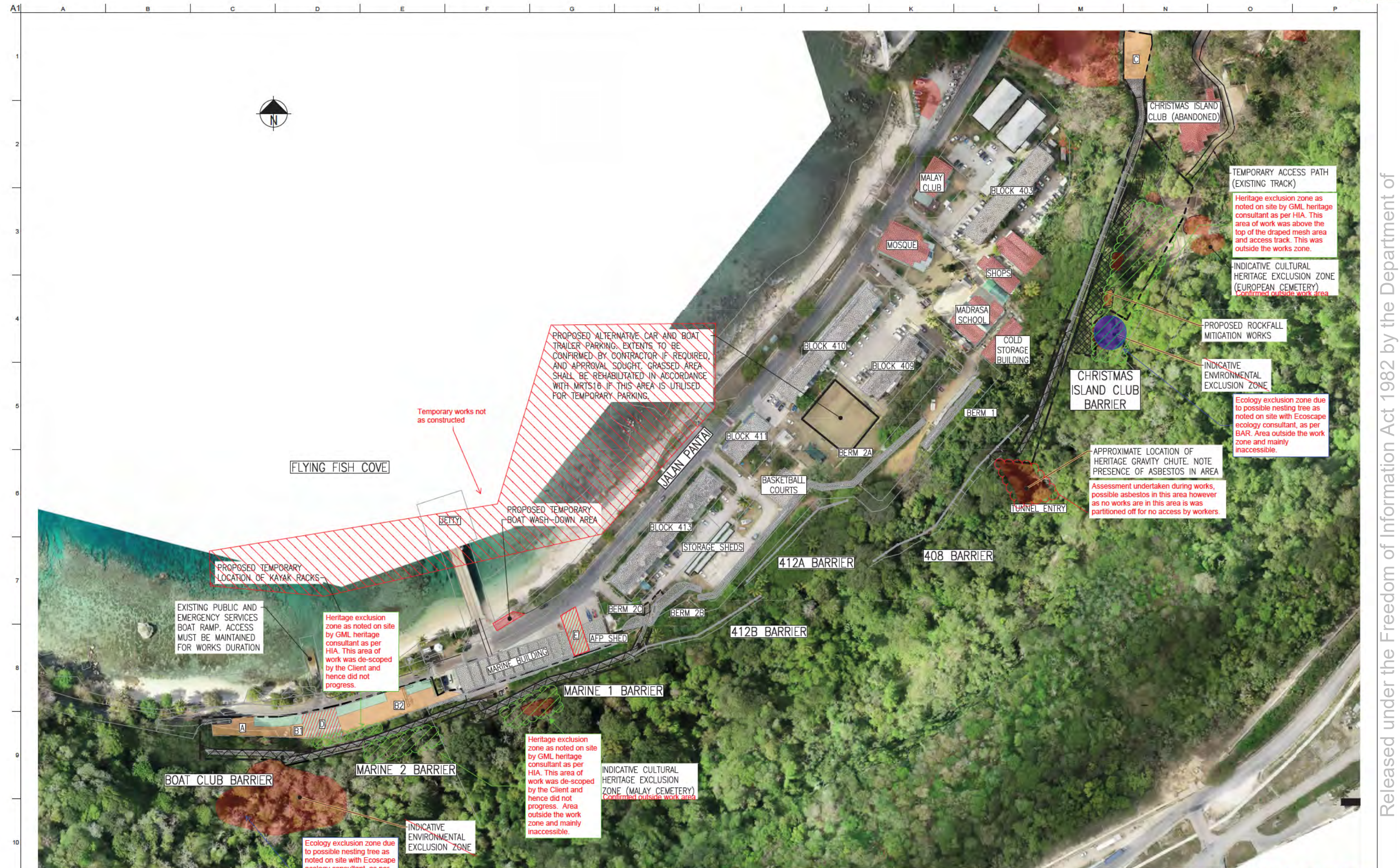
PLAN - VIEW 2  
SCALE 1:200

- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - THIS ECOLOGY EXCLUSION ZONE REPRESENTS THE APPROXIMATE LOCATION OF A SINGLE NESTING TREE WITH A 10m BUFFER ZONE. TREE LOCATION TO BE CONFIRMED BY THE CONTRACTORS SITE ENVIRONMENTAL REPRESENTATIVE, SURVEYED BY A SURVEYOR AND FLAGGED ON SITE PRIOR TO CONSTRUCTION. DRAPED MESH SHALL NOT IMPACT THIS TREE. SETBACK TO BE CONFIRMED PRIOR TO CONSTRUCTION IN CONSULTATION WITH THE SITE ENVIRONMENTAL REPRESENTATIVE AND SUPERINTENDENT.

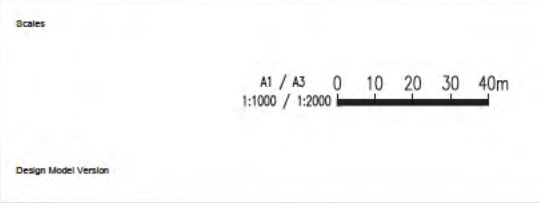
**ISSUED FOR CONSTRUCTION**

<p>Scale: A1 / A3 1:200 / 1:400</p>	<table border="1"> <thead> <tr> <th>Issue</th> <th>Date</th> <th>By</th> <th>Check</th> <th>Appr.</th> </tr> </thead> <tbody> <tr> <td>C</td> <td>19/10/20</td> <td>RB</td> <td>JG</td> <td>EF</td> </tr> <tr> <td colspan="5">Revised Post Demolition</td> </tr> <tr> <td>B</td> <td>24/08/20</td> <td>RB</td> <td>JG</td> <td>EF</td> </tr> <tr> <td colspan="5">Revised IFC</td> </tr> <tr> <td>A</td> <td>04/08/20</td> <td>RB</td> <td>JG</td> <td>EF</td> </tr> <tr> <td colspan="5">ISSUED FOR CONSTRUCTION</td> </tr> </tbody> </table>	Issue	Date	By	Check	Appr.	C	19/10/20	RB	JG	EF	Revised Post Demolition					B	24/08/20	RB	JG	EF	Revised IFC					A	04/08/20	RB	JG	EF	ISSUED FOR CONSTRUCTION					<p>Australian Government Department of Infrastructure, Transport, Regional Development and Communications</p>	<p>Client: AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS</p>	<p>Job Title: FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN</p>	<p><b>ARUP</b></p> <p>Level 4, 108 Wickham Street Forsyth Street, QLD, Australia, 4028 Tel: +61 (0)7 3207 9320 Fax: +61 (0)7 3207 9321 www.arup.com</p>	<p>CONSULT AUSTRALIA Member Firm Aus Pty Ltd Aust 18 900 961 165</p>	<p>Drawing Title: LANDSLIDE MITIGATION CHRISTMAS ISLAND CLUB DEMOLITION PLAN</p> <p>Drawing Status: <b>ISSUED FOR CONSTRUCTION</b></p> <p>Job No: 268575-00</p> <p>Drawing No: C-DD-02</p> <p>Issue: C</p>
Issue	Date	By	Check	Appr.																																						
C	19/10/20	RB	JG	EF																																						
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**ISSUED FOR CONSTRUCTION**



Issue	Date	By	Child	Appd
A	04/08/20	RB	JG	EF
ISSUED FOR CONSTRUCTION				

Australian Government  
Department of Infrastructure, Transport,  
Regional Development and Communications

Client  
**AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS**

Engineering Certification (CEng)  
Name: \_\_\_\_\_ Date: \_\_\_\_\_  
Signature: \_\_\_\_\_

Job Title  
**FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN**

Scale at A1: 1:1000  
Discipline: \_\_\_\_\_

**ARUP**

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Fortitude Valley QLD Australia 4006  
Tel: +61(0)7320 9320 Fax: +61(0)7320 9321  
www.arup.com

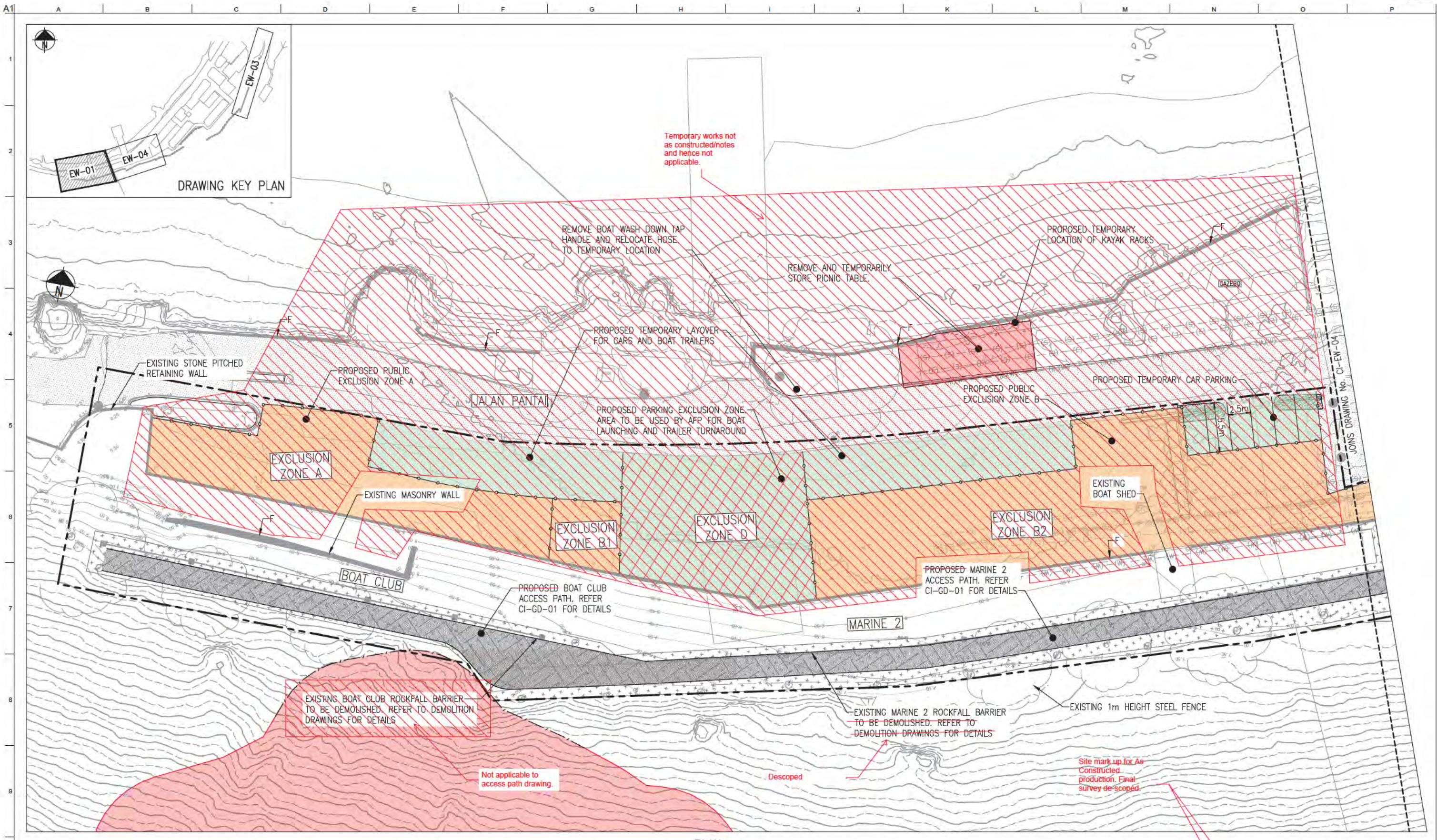
Drawing Title  
**LANDSLIDE MITIGATION EXISTING FEATURES SITE PLAN**

Drawing Status  
**ISSUED FOR CONSTRUCTION**

Job No: 268575-00  
Drawing No: CHEF-01  
Issue: A

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Temporary works not as constructed/notes and hence not applicable.

Not applicable to access path drawing.

Descope

Site mark up for As Constructed production. Final survey de-scoped

PLAN SCALE 1:200

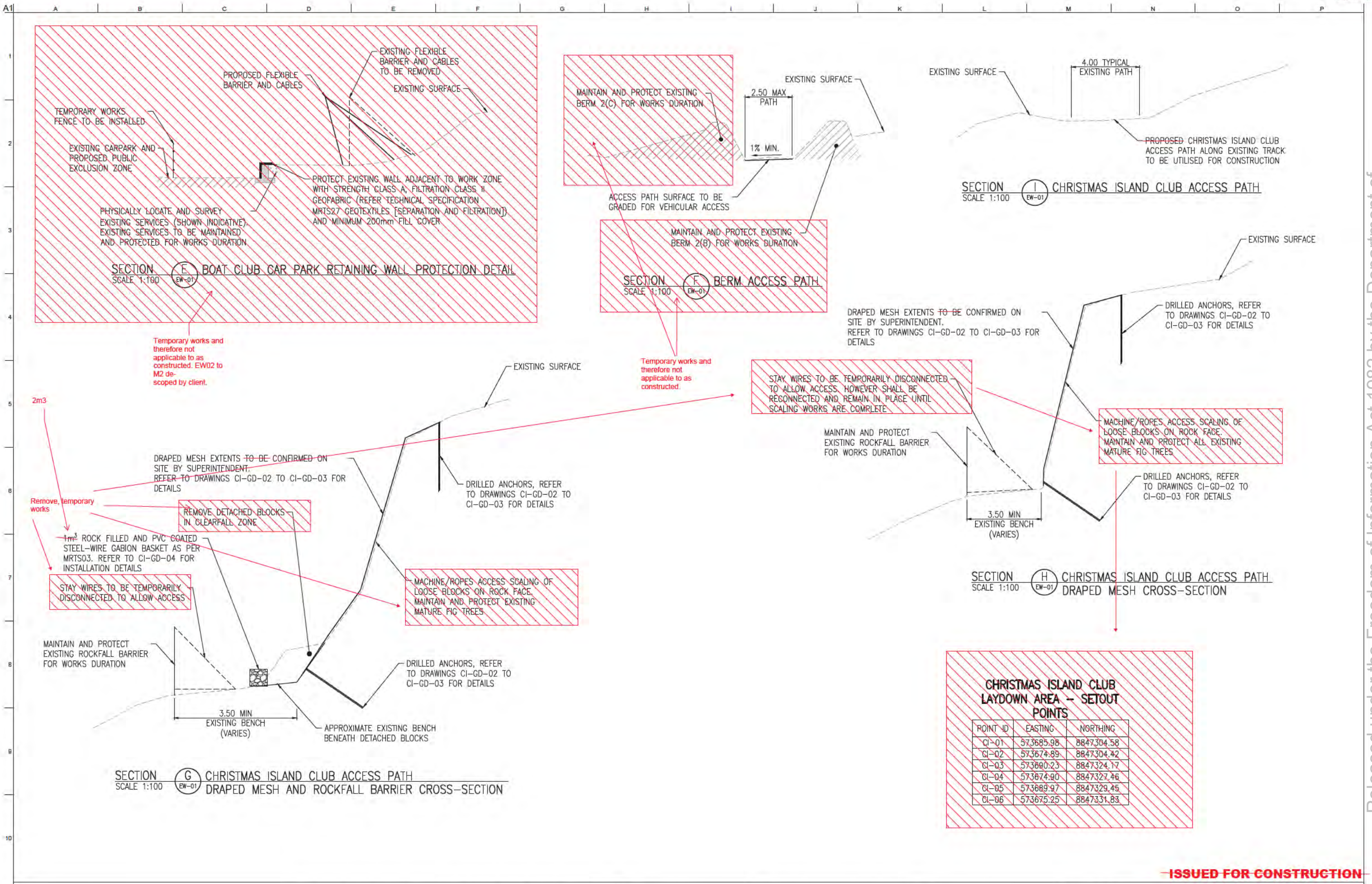
NOTES  
1. REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.

**ISSUED FOR CONSTRUCTION**

<p>Scales</p> <p>A1 / A3 1:200 / 1:400</p> <p>0 2 4 6 8m</p> <p>Design Model Version</p>	<table border="1"> <tr><td>Issue</td><td>Date</td><td>By</td><td>Chkd</td><td>Appd</td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> </table>	Issue	Date	By	Chkd	Appd						<table border="1"> <tr><td>Issue</td><td>Date</td><td>By</td><td>Chkd</td><td>Appd</td></tr> <tr><td>A</td><td>04/08/20</td><td>RB</td><td>JG</td><td>EF</td></tr> </table> <p>ISSUED FOR CONSTRUCTION</p>	Issue	Date	By	Chkd	Appd	A	04/08/20	RB	JG	EF	<p>Australian Government Department of Infrastructure, Transport, Regional Development and Communications</p>	<p>Client AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS</p> <p>Engineering Certification (CEng) Name: _____ Date: _____ Signature: _____</p>	<p>Job Title FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN</p> <p>Scale at A1: 1:200 Discipline: _____</p>	<p><b>ARUP</b></p> <p>Level 4 108 Wickham Street Fortitude Valley QLD Australia 4006 Tel +61(0)7320 9320 Fax +61(0)7320 9321 www.arup.com</p>	<p>Member Firm Aus Pty Ltd ABN 18 000 961 165</p>	<p>Drawing Title LANDSLIDE MITIGATION ACCESS PATH DETAILS SHEET 1</p> <p>Drawing Status <b>ISSUED FOR CONSTRUCTION</b></p> <p>Job No: 268575-00 Drawing No: CHEW-01 Issue: A</p>
Issue	Date	By	Chkd	Appd																								
Issue	Date	By	Chkd	Appd																								
A	04/08/20	RB	JG	EF																								

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Temporary works and therefore not applicable to as constructed. EW02 to M2 de-scoped by client.

Temporary works and therefore not applicable to as constructed.

Remove temporary works

**ISSUED FOR CONSTRUCTION**

Do not scale

Scales: A1 / A3 1:100 / 1:200

Issue	Date	By	CHKD	Appd
A	04/08/20	RB	JG	EF

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Australian Government  
Department of Infrastructure, Transport, Regional Development and Communications

Client: AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS

Job Title: FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN

ARUP  
Level 4 108 Wickham Street  
Fortitude Valley QLD Australia 4006  
Tel: +61 (0)7 320 9320 Fax: +61 (0)7 320 9321  
www.arup.com

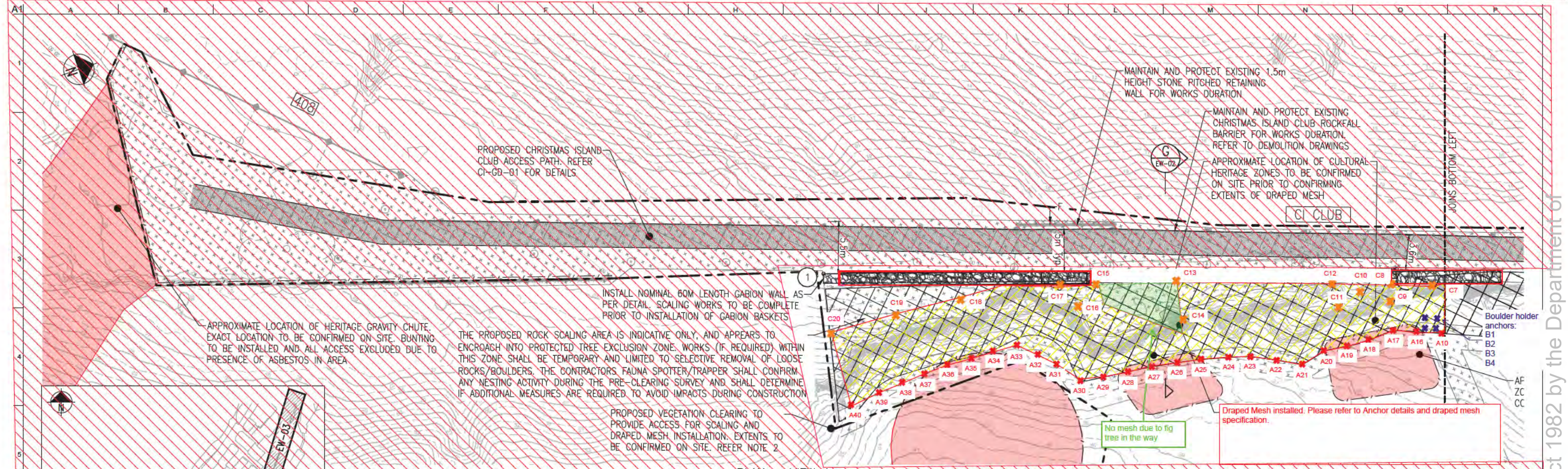
Engineering Certification (CEng)  
Name: \_\_\_\_\_ Date: \_\_\_\_\_  
Signature: \_\_\_\_\_

Scale at A1: 1:100  
Discipline: \_\_\_\_\_

Drawing Title: LANDSLIDE MITIGATION ACCESS PATH DETAILS TYPICAL SECTIONS  
Drawing Status: **ISSUED FOR CONSTRUCTION**  
Job No: 268575-00  
Drawing No: CHEW-02  
Issue: A

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PLAN - VIEW 1  
SCALE 1:250

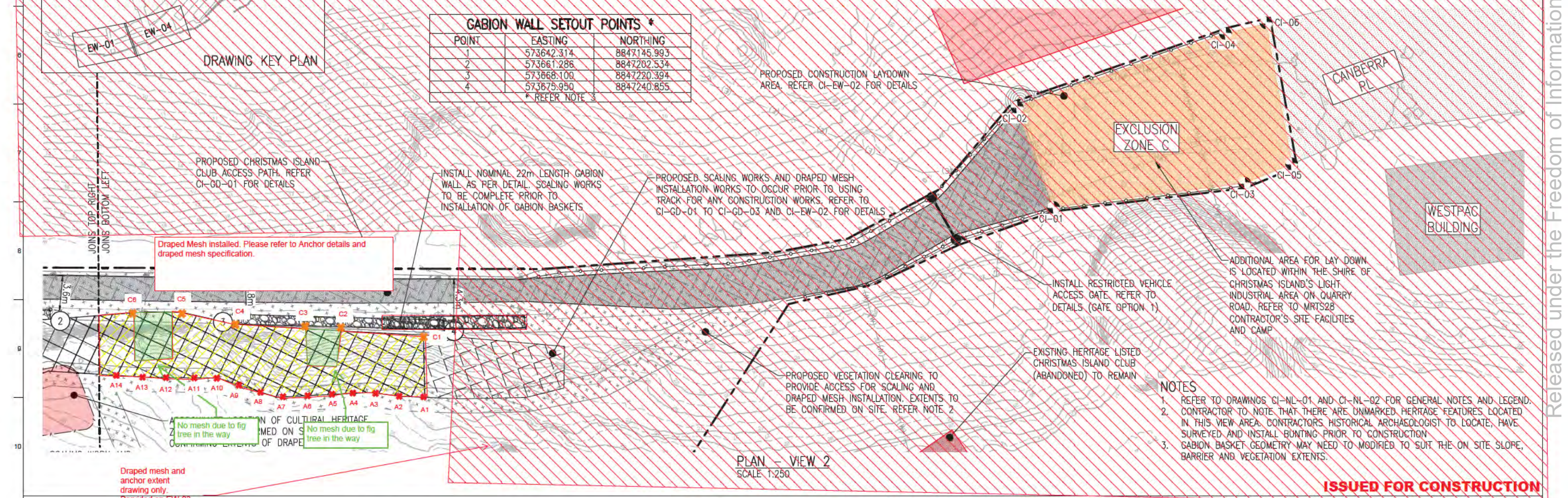
**GABION WALL SETOUT POINTS \***

POINT	EASTING	NORTHING
1	573642.314	8847145.993
2	573661.286	8847202.534
3	573668.100	8847220.394
4	573675.950	8847240.855

\* REFER NOTE 3



DRAWING KEY PLAN



PLAN - VIEW 2  
SCALE 1:250

- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - CONTRACTOR TO NOTE THAT THERE ARE UNMARKED HERITAGE FEATURES LOCATED IN THIS VIEW AREA. CONTRACTORS HISTORICAL ARCHAEOLOGIST TO LOCATE, HAVE SURVEYED AND INSTALL BUNTING PRIOR TO CONSTRUCTION
  - GABION BASKET GEOMETRY MAY NEED TO MODIFIED TO SUIT THE ON SITE SLOPE, BARRIER AND VEGETATION EXTENTS.

**ISSUED FOR CONSTRUCTION**

Scales: A1 / A3 0 2 4 6 8m 1:200 / 1:400

Design Model Version

Issue	Date	By	Chkd	Appd
A	04/08/20	RB	JG	EF

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Job Title: FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN

Scale at A1: 1:200

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Fortitude Valley QLD Australia 4006  
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www.arup.com

CONSULT AUSTRALIA  
Member Firm  
Aus Pty Ltd  
ABN 18 000 960 165

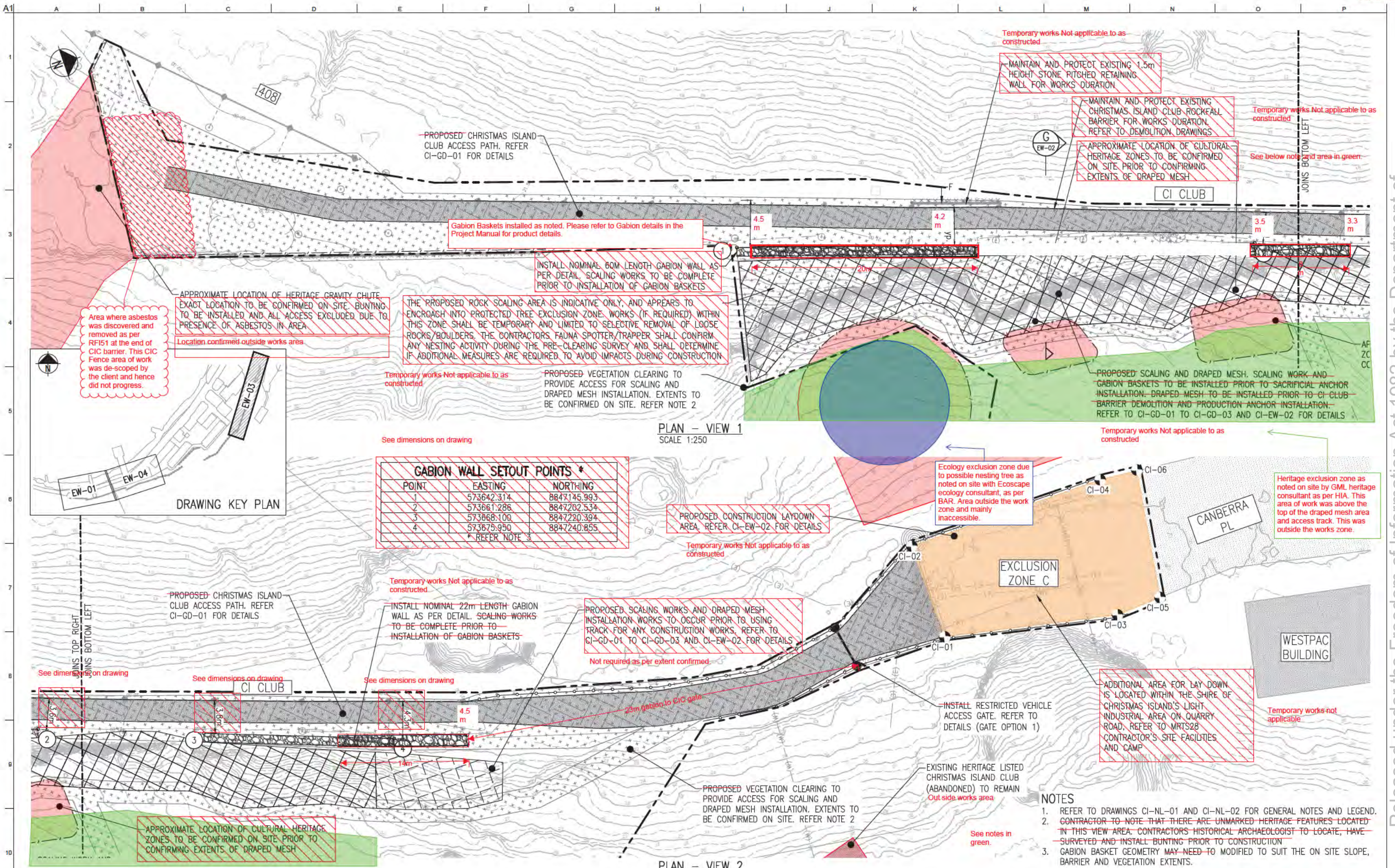
Drawing Title: LANDSLIDE MITIGATION ACCESS PATH DETAILS SHEET 2

Drawing Status: ISSUED FOR CONSTRUCTION

Job No: 268575-00 Drawing No: CHEW-03 Issue: A

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**GABION WALL SETOUT POINTS \***

POINT	EASTING	NORTHING
1	573642.314	8847145.993
2	573661.286	8847202.534
3	573668.100	8847220.394
4	573675.950	8847240.855

\* REFER NOTE 3

PLAN - VIEW 1  
SCALE 1:250

PLAN - VIEW 2  
SCALE 1:250

- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - CONTRACTOR TO NOTE THAT THERE ARE UNMARKED HERITAGE FEATURES LOCATED IN THIS VIEW AREA. CONTRACTORS HISTORICAL ARCHAEOLOGIST TO LOCATE, HAVE SURVEYED AND INSTALL BUNTING PRIOR TO CONSTRUCTION.
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**ISSUED FOR CONSTRUCTION**

Scales: A1 / A3 1:200 / 1:400

Design Model Version

Issue	Date	By	Child	Appd
A	04/08/20	RB	JG	EF

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Client  
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REGIONAL DEVELOPMENT  
AND COMMUNICATIONS

Job Title  
FLYING FISH COVE  
CHRISTMAS ISLAND  
LANDSLIDE MITIGATION  
DETAILED DESIGN

**ARUP**  
Level 4 108 Wickham Street  
Fortitude Valley QLD Australia 4006  
Tel: +61 (0)7 320 9320 Fax: +61 (0)7 320 9321  
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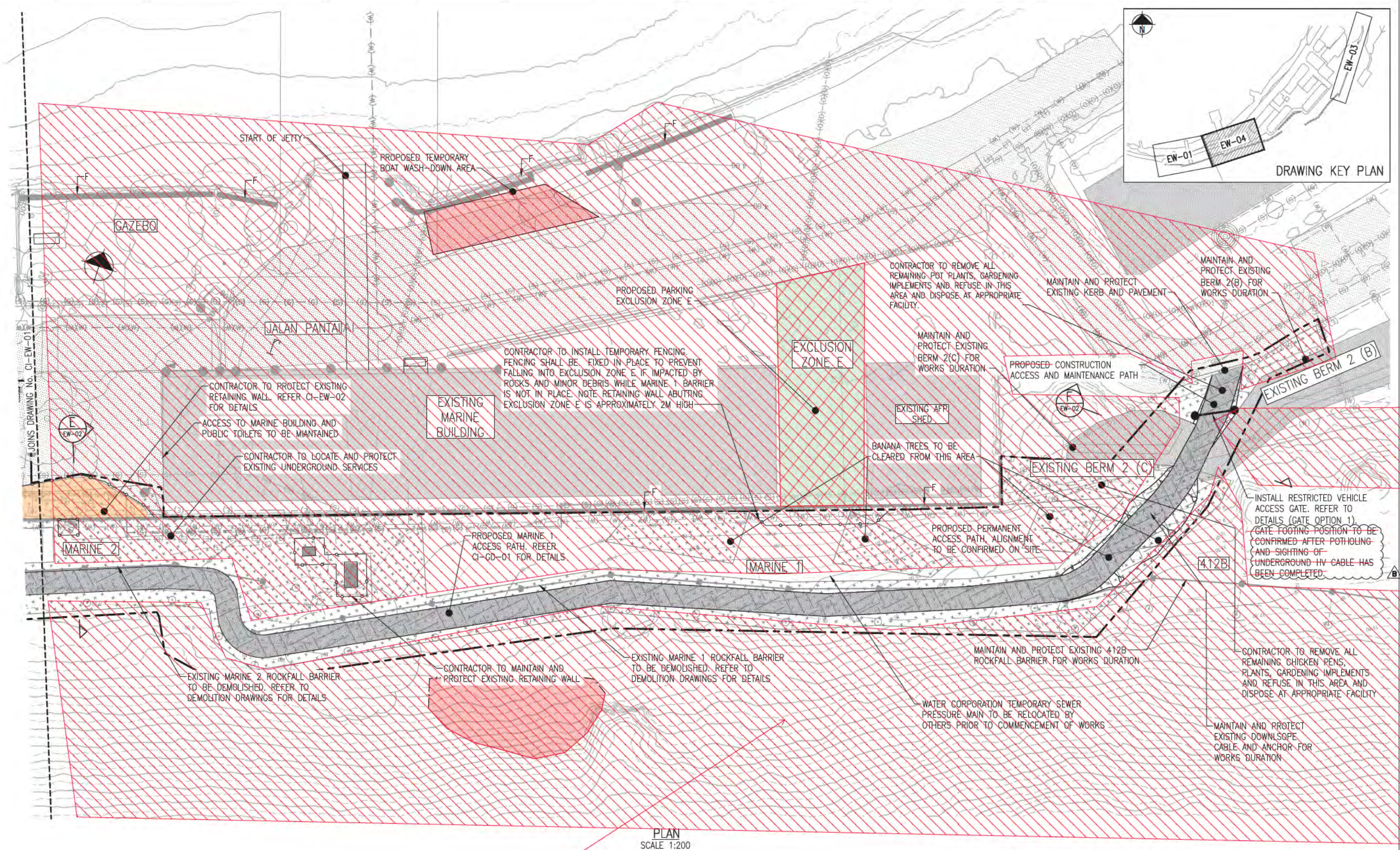
Drawing Title  
LANDSLIDE MITIGATION  
ACCESS PATH DETAILS  
SHEET 2

Drawing Status  
**ISSUED FOR CONSTRUCTION**

Job No: 268575-00  
Drawing No: CHEW-03  
Issue: A

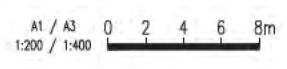
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PLAN  
SCALE 1:200

NOTES  
1. REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.

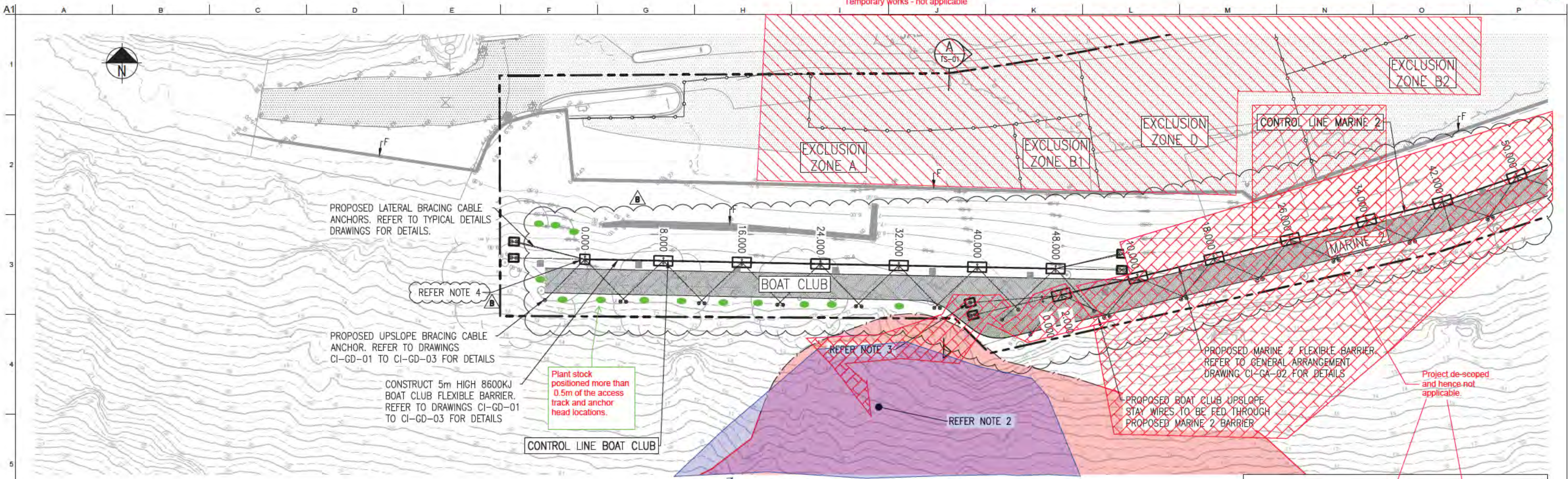


Australian Government  
Department of Infrastructure, Transport,  
Regional Development and Communications

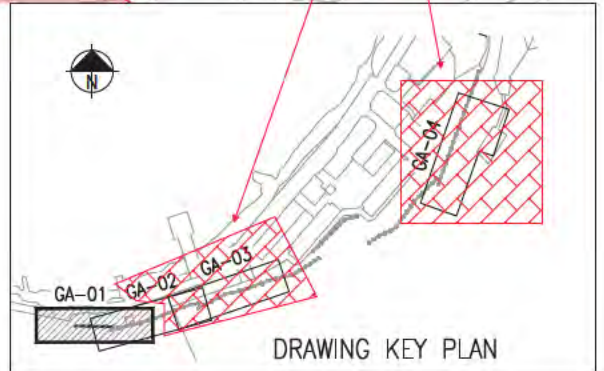
ARUP



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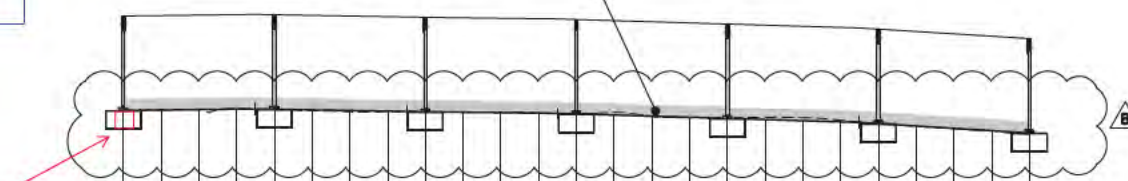
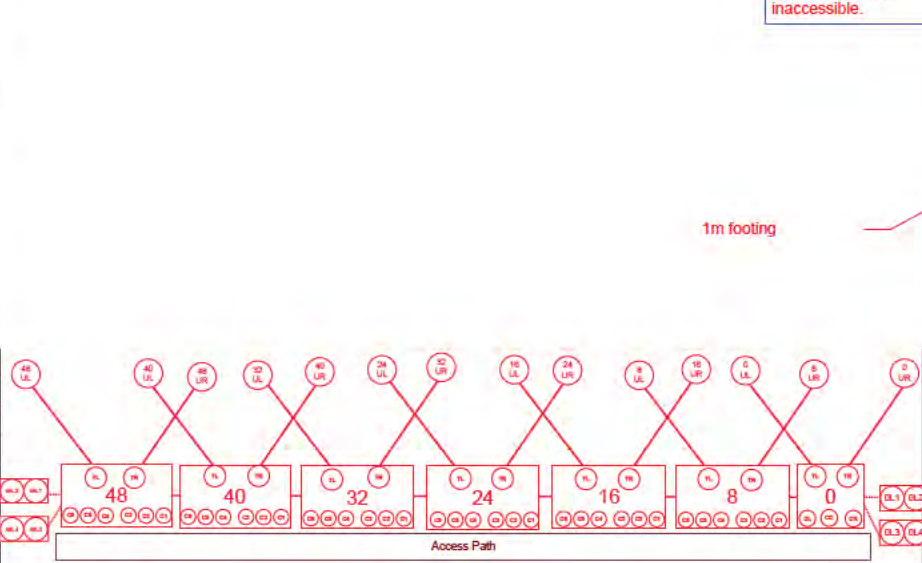


PLAN  
SCALE 1:200



Ecology exclusion zone due to possible nesting tree as noted on site with Ecoscape ecology consultant, as per BAR. Area outside the work zone and mainly inaccessible.

CRAB APRON TO BE ATTACHED TO UPSLOPE SIDE OF BARRIER, REFER TYPICAL DETAILS



Chainage	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	
Fence Height	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Design Height*	9.354	9.379	9.404	9.429	9.424	9.389	9.354	9.319	9.289	9.264	9.239	9.214	9.171	9.111	9.051	8.969	8.931	8.871	8.811	8.751	8.689	8.659	8.534	8.409	8.284	8.159
Natural Surface	9.354	9.387	9.433	9.457	9.406	9.345	9.284	9.285	9.268	9.258	9.248	9.229	9.168	9.254	9.111	9.040	8.969	8.974	8.979	8.972	8.836	8.689	8.573	8.382	8.285	8.092

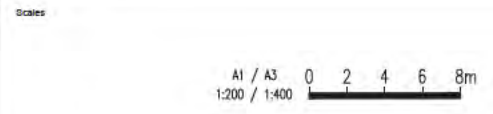
\*CORRESPONDS TO TOP OF CONCRETE FOOTING HEIGHT  
VERTICAL SCALE 1:200  
HORIZONTAL SCALE 1:200  
**LONGITUDINAL SECTION - BOAT CLUB**

- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - THIS ECOLOGY EXCLUSION ZONE REPRESENTS THE APPROXIMATE LOCATION OF SINGLE NESTING TREE WITH A 10m BUFFER ZONE. TREE LOCATION TO BE CONFIRMED BY THE CONTRACTORS SITE ENVIRONMENTAL REPRESENTATIVE, SURVEYED BY A SURVEYOR AND FLAGGED ON SITE PRIOR TO CONSTRUCTION. DRAPED MESH SHALL NOT IMPACT THIS TREE. SETBACK TO BE CONFIRMED PRIOR TO CONSTRUCTION IN CONSULTATION WITH THE SITE ENVIRONMENTAL REPRESENTATIVE AND SUPERINTENDENT.
  - PROPOSED ANCHOR POSITION TO BE CONFIRMED ON SITE AFTER EXTENT OF DEMOLISHED ANCHORS ARE KNOWN.
  - CHAINAGE 0 POST FOOTINGS AS PER CI-GD-04 AND CI-GD-12.

See note in Blue.

Site mark up for As Constructed production. Final survey de-scoped.

**ISSUED FOR CONSTRUCTION**



Issue	Date	By	Child	Appd

B	19/10/21	JL	JG	EF
Revised As Clouded				
A	04/08/20	RB	JG	EF
ISSUED FOR CONSTRUCTION				
Issue	Date	By	Child	Appd

Australian Government  
Department of Infrastructure, Transport, Regional Development and Communications

Client  
**AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS**  
Engineering Certification (CEng)  
Name: \_\_\_\_\_ Date: \_\_\_\_\_  
Signature: \_\_\_\_\_

Job Title  
**FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN**  
Scale at A1 1:200  
Discipline

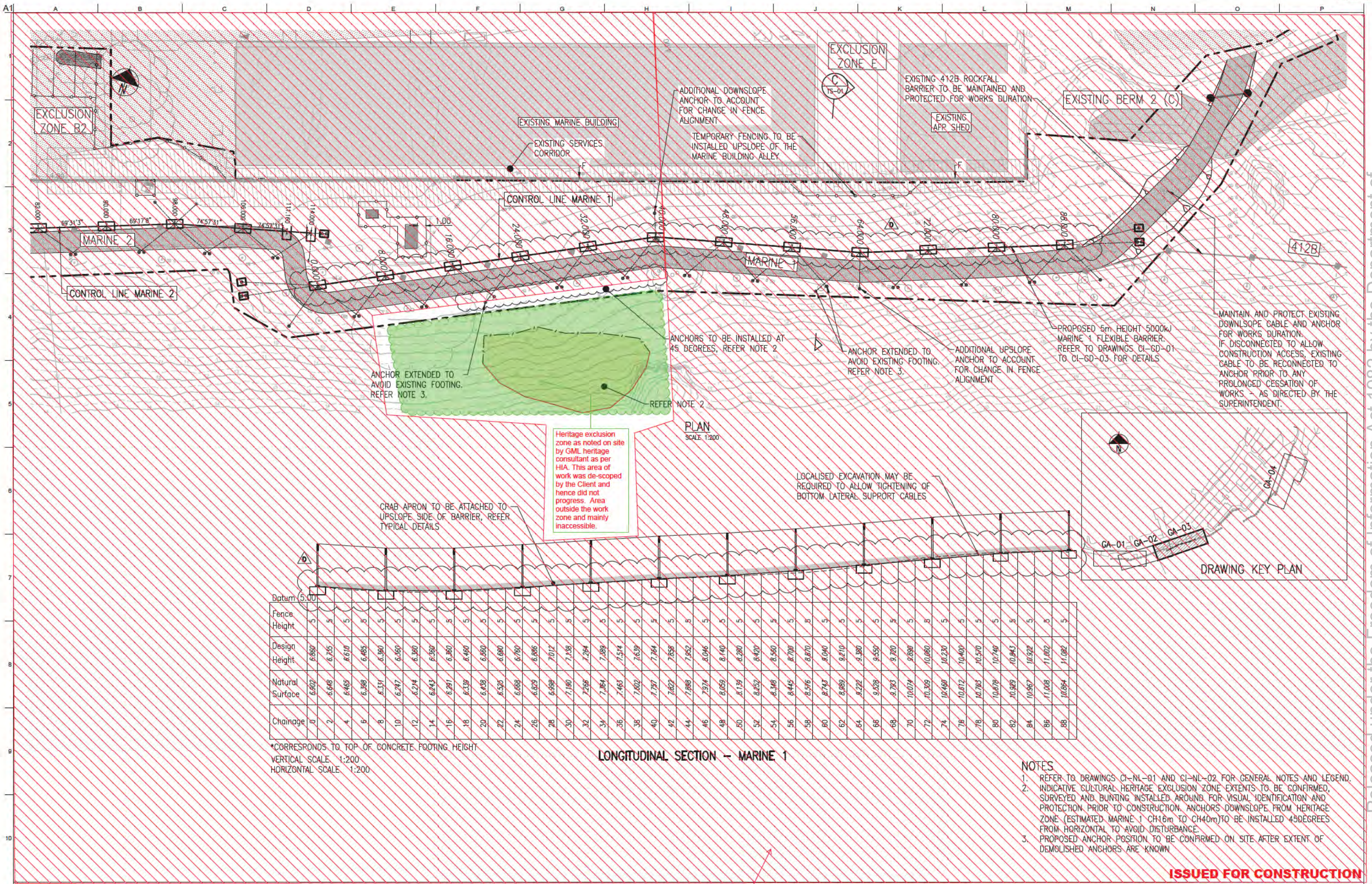
**ARUP**  
Level 4 108 Wickham Street  
Fortitude Valley QLD Australia 4006  
Tel: +61 (0)7 320 9320 Fax: +61 (0)7 320 9321  
www.arup.com

CONSULT AUSTRALIA  
Member Firm  
Aus Pty Ltd  
ABN 18 000 968 185

Drawing Title  
**LANDSLIDE MITIGATION BOAT CLUB GENERAL ARRANGEMENT**  
Drawing Status  
**ISSUED FOR CONSTRUCTION**  
Job No: **268575-00** Drawing No: **CI-GA-01** Issue: **B**

**DRAWING COLOUR CODED - PRINT ALL COPIES IN COLOUR**

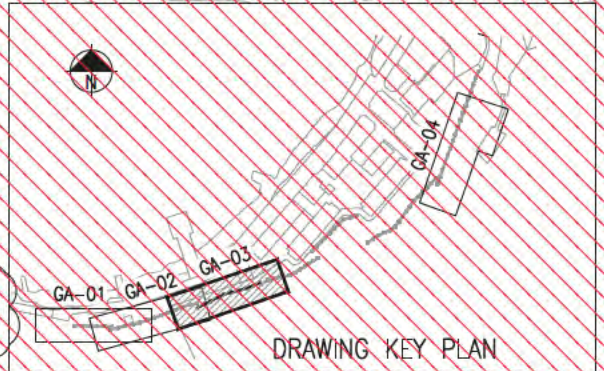




Datum	5.00
Fence Height	5
Design Height	6.667
Natural Surface	6.602
Chainage	0
	2
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LONGITUDINAL SECTION -- MARINE 1

\*CORRESPONDS TO TOP OF CONCRETE FOOTING HEIGHT  
 VERTICAL SCALE 1:200  
 HORIZONTAL SCALE 1:200



- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - INDICATIVE CULTURAL HERITAGE EXCLUSION ZONE EXTENTS TO BE CONFIRMED, SURVEYED AND BUNTING INSTALLED AROUND FOR VISUAL IDENTIFICATION AND PROTECTION PRIOR TO CONSTRUCTION. ANCHORS DOWNSLOPE FROM HERITAGE ZONE (ESTIMATED MARINE 1 CH16m TO CH40m) TO BE INSTALLED 45DEGREES FROM HORIZONTAL TO AVOID DISTURBANCE.
  - PROPOSED ANCHOR POSITION TO BE CONFIRMED ON SITE AFTER EXTENT OF DEMOLISHED ANCHORS ARE KNOWN

**ISSUED FOR CONSTRUCTION**

Scales

A1 / A3  
1:200 / 1:400

0 2 4 6 8m

Design Model Version

D	22/08/21	JL	JG	EF
Revised As Clouded				
Issue	Date	By	CHKD	Appd

C	13/10/20	RB	JG	EF
Marine 2 Compression Strut				
B	24/08/20	RB	JG	EF
Revised IFC				
A	04/08/20	RB	JG	EF
ISSUED FOR CONSTRUCTION				
Issue	Date	By	CHKD	Appd

Australian Government  
 Department of Infrastructure, Transport,  
 Regional Development and Communications

Project descope and hence not applicable.

Client  
 AUSTRALIAN GOVERNMENT DPT  
 OF INFRASTRUCTURE, TRANSPORT,  
 REGIONAL DEVELOPMENT  
 AND COMMUNICATIONS

Engineering Certification (CEng)  
 Name: \_\_\_\_\_ Date: \_\_\_\_\_  
 Signature: \_\_\_\_\_

Job Title  
 FLYING FISH COVE  
 CHRISTMAS ISLAND  
 LANDSLIDE MITIGATION  
 DETAILED DESIGN

Scale at A1 1:200  
 Discipline

**ARUP**

Level 4 108 Wickham Street  
 Fortitude Valley QLD Australia 4006  
 Tel: +61(0)7320 9320 Fax: +61(0)7320 9321  
 www.arup.com

Drawing Title  
 LANDSLIDE MITIGATION  
 MARINE 1  
 GENERAL ARRANGEMENT

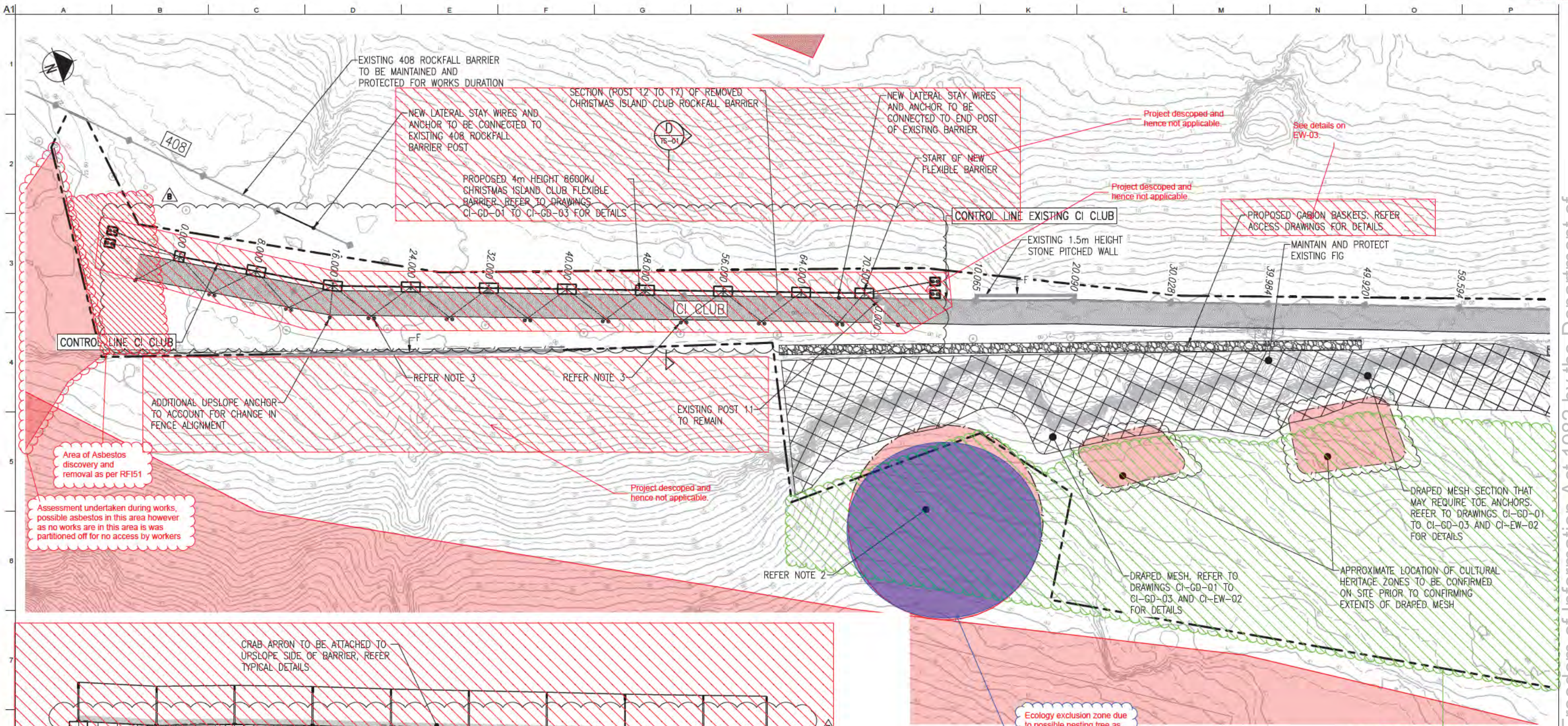
Drawing Status  
**ISSUED FOR CONSTRUCTION**

Job No  
 268575-00

Drawing No  
 CI-GA-03

Issue  
 D

**DRAWING COLOUR CODED - PRINT ALL COPIES IN COLOUR**

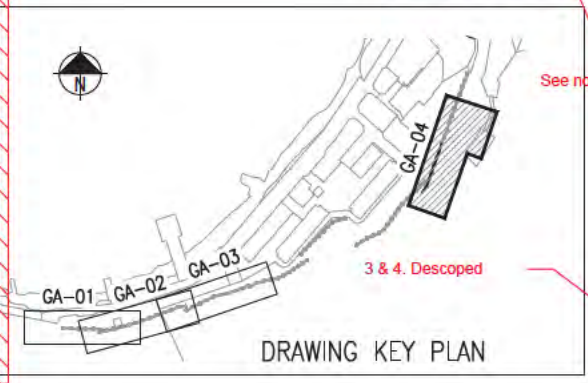


CRAB APRON TO BE ATTACHED TO UPSLOPE SIDE OF BARRIER, REFER TYPICAL DETAILS

Datum	19.00																																				
Fence Height	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4																	
Design Height	22.258	22.153	22.048	21.943	21.838	21.733	21.628	21.523	21.418	21.313	21.208	21.103	20.998	20.893	20.788	20.683	20.578	20.473	20.368	20.263																	
Natural Surface	22.259	22.149	22.033	21.918	21.803	21.688	21.573	21.458	21.343	21.228	21.113	20.998	20.883	20.768	20.653	20.538	20.423	20.308	20.193	20.078																	
Chainage	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	70.5

\*CORRESPONDS TO TOP OF CONCRETE FOOTING HEIGHT  
 VERTICAL SCALE 1:200  
 HORIZONTAL SCALE 1:200

LONGITUDINAL SECTION - CI CLUB



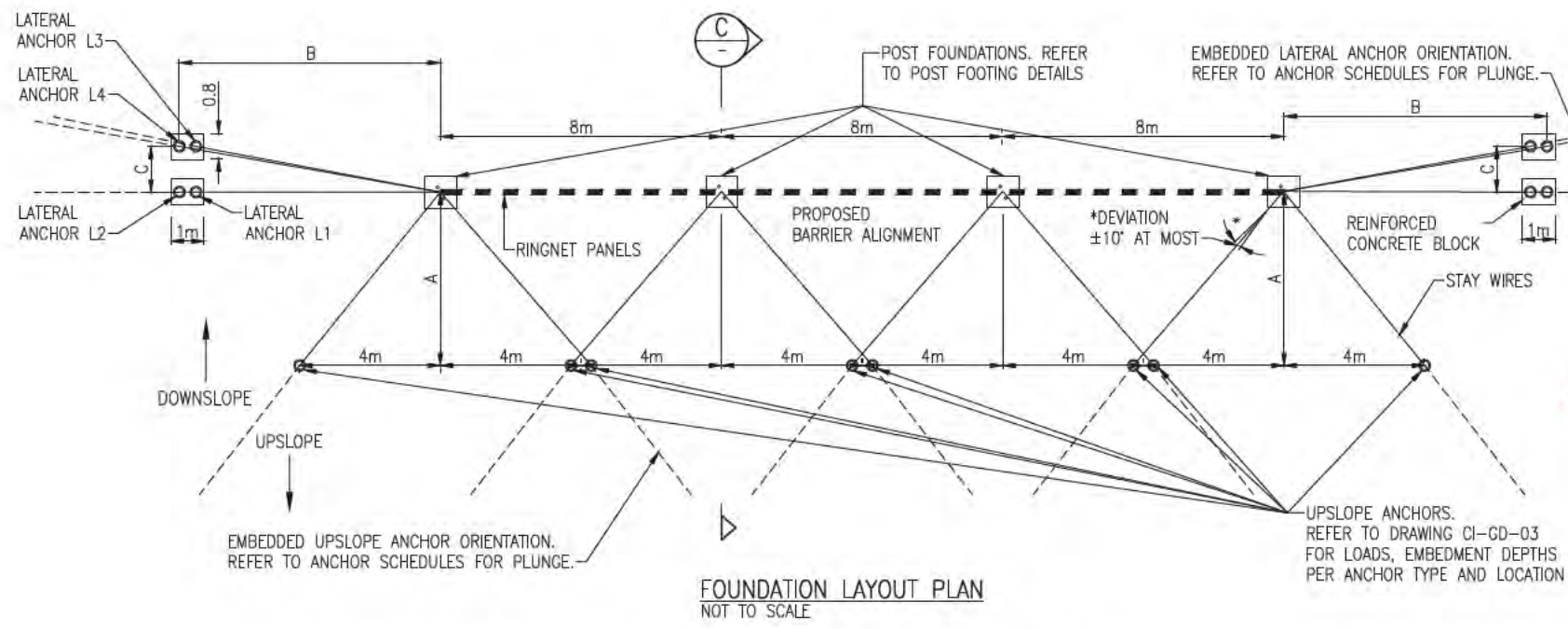
- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - THIS ECOLOGY EXCLUSION ZONE REPRESENTS THE APPROXIMATE LOCATION OF SINGLE NESTING TREE WITH A 10m BUFFER ZONE. TREE LOCATION TO BE CONFIRMED BY THE CONTRACTORS SITE ENVIRONMENTAL REPRESENTATIVE, SURVEYED BY A SURVEYOR AND FLAGGED ON SITE PRIOR TO CONSTRUCTION. DRAPED MESH SHALL NOT IMPACT THIS TREE. SETBACK TO BE CONFIRMED PRIOR TO CONSTRUCTION IN CONSULTATION WITH THE SITE ENVIRONMENTAL REPRESENTATIVE AND SUPERINTENDENT.
  - PROPOSED ANCHOR POSITION TO BE CONFIRMED ON SITE AFTER EXTENT OF DEMOLISHED ANCHORS ARE KNOWN.
  - CHAINAGE B POST FOOTINGS AS PER CI-GD-10 AND CI-GD-12.

**ISSUED FOR CONSTRUCTION**

<p>Scales</p> <p>Project descope and hence not applicable</p> <p>A1 / A3 1:200 / 1:400</p> <p>0 2 4 6 8m</p>	<table border="1"> <tr> <th>Issue</th> <th>Date</th> <th>By</th> <th>Chk</th> <th>Appd</th> </tr> <tr> <td>B</td> <td>19/10/21</td> <td>JL</td> <td>JG</td> <td>EF</td> </tr> <tr> <td colspan="5">Revised As Clouded</td> </tr> <tr> <td>A</td> <td>04/08/20</td> <td>RB</td> <td>JG</td> <td>EF</td> </tr> <tr> <td colspan="5">ISSUED FOR CONSTRUCTION</td> </tr> </table>	Issue	Date	By	Chk	Appd	B	19/10/21	JL	JG	EF	Revised As Clouded					A	04/08/20	RB	JG	EF	ISSUED FOR CONSTRUCTION					<p>Australian Government                  Department of Infrastructure, Transport, Regional Development and Communications</p>	<p>Client                  AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS</p> <p>Job Title                  FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN</p> <p>Scale at A1                  1:200</p>	<p>ARUP</p> <p>Level 4 108 Wickham Street                  Fortitude Valley QLD Australia 4006                  Tel: +61 (0)7 320 9320 Fax: +61 (0)7 320 9321                  www.arup.com</p>	<p>Drawing Title                  LANDSLIDE MITIGATION CHRISTMAS ISLAND CLUB GENERAL ARRANGEMENT</p> <p>Drawing Status  <b>ISSUED FOR CONSTRUCTION</b></p> <p>Job No                  268575-00</p> <p>Drawing No                  CI-GA-04</p> <p>Issue                  B</p>
Issue	Date	By	Chk	Appd																										
B	19/10/21	JL	JG	EF																										
Revised As Clouded																														
A	04/08/20	RB	JG	EF																										
ISSUED FOR CONSTRUCTION																														

**DRAWING COLOUR CODED - PRINT ALL COPIES IN COLOUR**

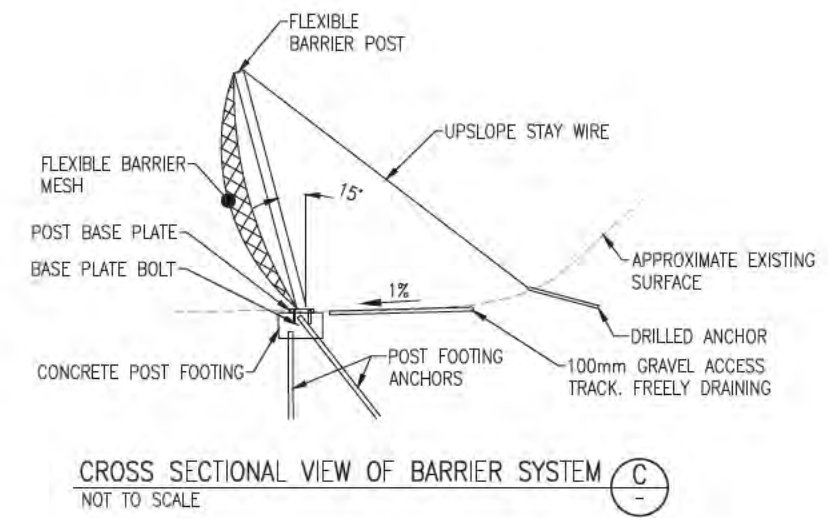
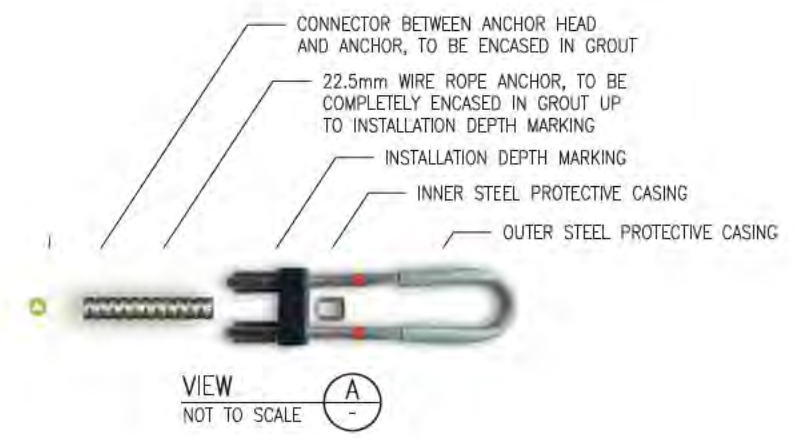
Released under the Freedom of Information Act 1982 by the Department of Infrastructure, Transport, Regional Development, Communications, Sport and the Arts



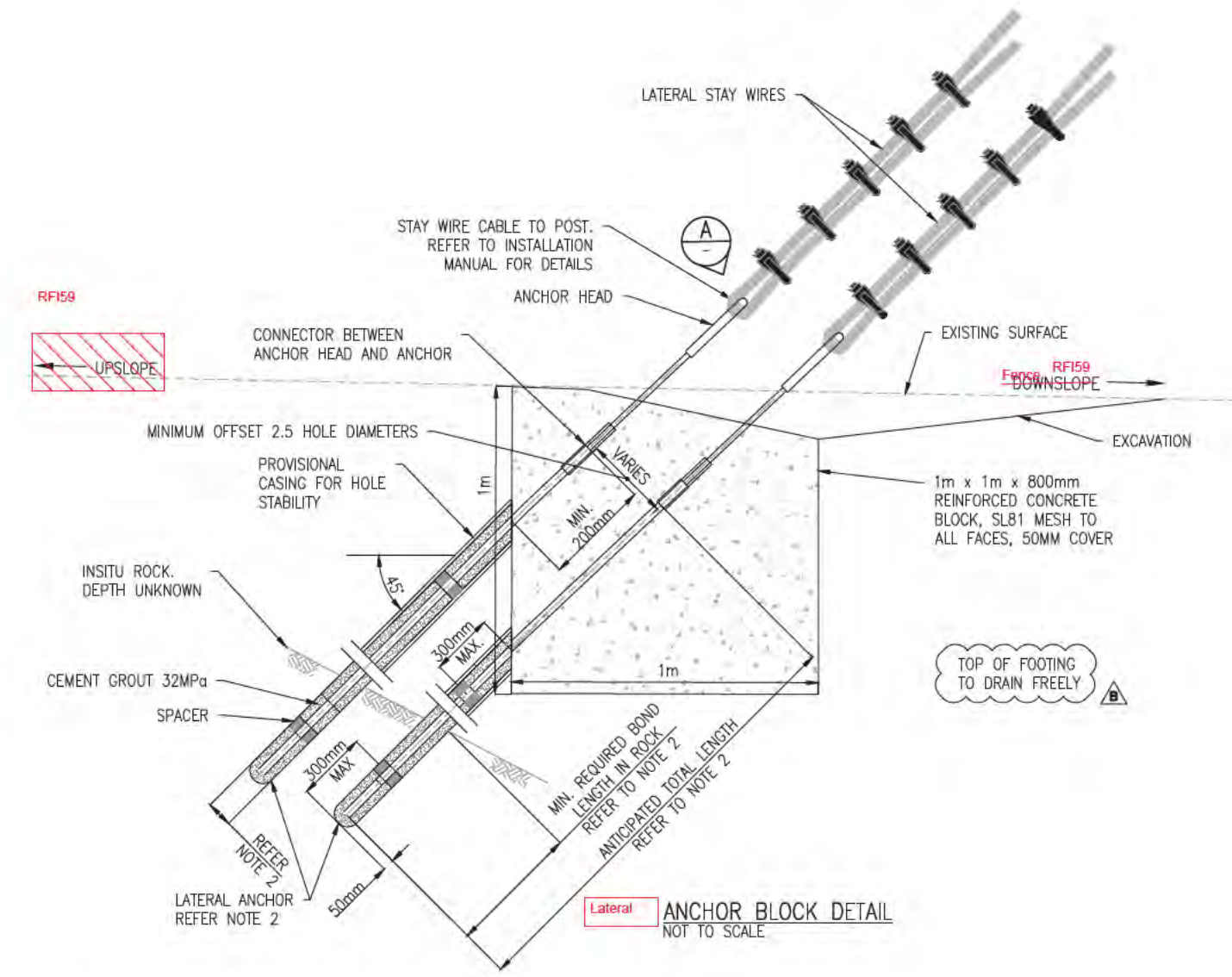
**FLEXIBLE BARRIER GEOMETRY**

FLEXIBLE BARRIER	BARRIER HEIGHT (m)	TOTAL BARRIER LENGTH (m)	POSTS (No.)	BARRIER ENERGY CAPACITY (kJ)	A (m) MINIMUM	B (m)	C (m)
BOAT CLUB BARRIER	5	48	7	8600	4	7.5	1.65
MARINE 2	4	112	15	5000	3	9	1.3
MARINE 1	5	88	12	5000	4	9	1.65
CHRISTMAS ISLAND CLUB	4	70.5	10	8600	3	7.5	1.3

Project descope and hence not applicable.



- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - INSTALL GROUND ANCHORS IN ACCORDANCE WITH GROUND ANCHOR SCHEDULES SHOWN ON DRAWING CI-GD-03.



**ISSUED FOR CONSTRUCTION**

<p>Scale: N.T.S.</p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td>Issue</td><td>Date</td><td>By</td><td>Child</td><td>Appr</td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> </table>	Issue	Date	By	Child	Appr																<p style="text-align: center;"> Australian Government Department of Infrastructure, Transport, Regional Development and Communications</p>	<p>Client: AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS</p> <p>Job Title: FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN</p> <p>Scale: N.T.S.</p> <p>Discipline:</p>	<p style="text-align: center;"><b>ARUP</b></p> <p style="font-size: small;">Level 4 108 Wickham Street Fortitude Valley QLD Australia 4006 Tel: +61 (0)7 320 9320 Fax: +61 (0)7 320 9321 www.arup.com</p> <p style="text-align: center;"> CONSULT AUSTRALIA Member Firm Aus Pty Ltd ABN 18 001 968 185</p>	<p>Drawing Title: LANDSLIDE MITIGATION TYPICAL DETAILS SHEET 1</p> <p>Drawing Status: <b>ISSUED FOR CONSTRUCTION</b></p> <p>Job No: 268575-00 Drawing No: CI-GD-01 Issue: B</p>
Issue	Date	By	Child	Appr																					

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### GROUND ANCHOR SCHEDULE - BOAT CLUB BARRIER

ANCHOR LOCATION	ANCHOR TYPE	NUMBER OF ANCHORS	ANCHOR INCLINATION FROM HORIZONTAL	ULTIMATE LOAD PER ANCHOR	DRILLHOLE DIAMETER	ROCK EMBEDMENT			COLLUVIUM EMBEDMENT
						ESTIMATED SOIL DEPTH	MINIMUM BOND LENGTH IN SLIGHTLY WEATHERED ROCK	ESTIMATED TOTAL ANCHOR LENGTH	ESTIMATED ANCHOR LENGTH
			deg	kN	mm	m	m	m	m
Upslope Anchors	52/26 self drilling anchor	14	15	500	125	7	3.5	10.5	8
Lateral Anchors	L1: 52/26 self drilling anchor	2	45	600	125	11	4	15	9
	L2: 52/26 self drilling anchor	2	45	600	125	11	4	15	9
	L3: 52/26 self drilling anchor	2	45	600	125	11	4	15	9
	L4: 40/16 self drilling anchor	2	45	300	85	11	3	14	6
Post Compression Anchors	52/26 self drilling anchor	42	90	400	125	7	5	12	6
Post Tension Anchors	52/26 self drilling anchor	14	45	445	125	7	3	10	7

### PULL-OUT TEST SCHEDULE - PRODUCTION ANCHORS

FLEXIBLE BARRIER	ANCHOR TYPE	NUMBER OF PULL-OUT TESTS	TEST LOAD
Boat Club Barrier	Upslope Production Anchor	3	Ultimate Load
	Lateral Production Anchor	1	Ultimate Load
	Post Tension Production Anchor	2	Ultimate Load
Marine 2 Barrier	Upslope Production Anchor	3	Ultimate Load
	Lateral Production Anchor	1	Ultimate Load
	Post Tension Production Anchor	4	Ultimate Load
Marine 1 Barrier	Upslope Production Anchor	3	Ultimate Load
	Lateral Production Anchor	1	Ultimate Load
	Post Tension Production Anchor	4	Ultimate Load
Christmas Island Club Barrier	Upslope Production Anchor	3	Ultimate Load
	Lateral Production Anchor	1	Ultimate Load
	Post Tension Production Anchor	3	Ultimate Load

Project descope and hence not applicable.

Project descope and hence not applicable.

### GROUND ANCHOR SCHEDULE - MARINE 2

ANCHOR LOCATION	ANCHOR TYPE	NUMBER OF ANCHORS	ANCHOR INCLINATION FROM HORIZONTAL	ULTIMATE LOAD PER ANCHOR	DRILLHOLE DIAMETER	ROCK EMBEDMENT			COLLUVIUM EMBEDMENT
						ESTIMATED SOIL DEPTH	MINIMUM BOND LENGTH IN SLIGHTLY WEATHERED ROCK	ESTIMATED TOTAL ANCHOR LENGTH	ESTIMATED ANCHOR LENGTH
			deg	kN	mm	m	m	m	m
Upslope Anchors*	52/26 self drilling anchor	28	15	340	125	8	2.5	10.5	6
Lateral Anchors*	L1: 52/26 self drilling anchor	1	45	600	125	14	4	18	9
	L2: 52/26 self drilling anchor	1	45	600	125	14	4	18	9
	L3: N/A	-	-	-	-	-	-	-	-
	L4: 40/16 self drilling anchor	1	45	280	85	14	3	17	6
Post Compression Anchors*	52/26 self drilling anchor	56	90	400	125	8	5	13	6
Post Tension Anchors*	40/16 self drilling anchor	28	45	275	85	8	3	11	6
Barrier Alignment Adjustment Anchors*	40/16 self drilling anchor	4	15	310	85	8	3	11	6

\*Not applicable to CH114 end post and compressions strut post. Refer to CI-GD-08 for relevant ground anchor schedule information.

### PULL-OUT TEST SCHEDULE - SACRIFICIAL ANCHORS

FLEXIBLE BARRIER	ANCHOR TYPE	NUMBER OF PULL-OUT TESTS	ESTIMATED ANCHOR LENGTH	ROCK EMBEDMENT		COLLUVIUM EMBEDMENT	
				BONDED ANCHOR LENGTH	TEST LOAD	BOND LENGTH	TEST LOAD
				m	(kN)	m	(kN)
Boat Club Barrier	Upslope Sacrificial Anchor, chainage 15m	1	Refer anchor schedule	1.5	360kN	-	-
	Lateral Sacrificial Anchor, chainage 48m	1	Refer anchor schedule	1.5	360kN	-	-
	Post tension Sacrificial Anchor, chainage 30m	1	Refer anchor schedule	1.5	360kN	-	-
Marine 2 Barrier	Upslope Sacrificial Anchor, chainage 40m	1	Refer anchor schedule	1.5	360kN	-	-
	Lateral Sacrificial Anchor, chainage 116m	1	Refer anchor schedule	1.5	360kN	-	-
	Post tension Sacrificial Anchor, chainage 75m	1	Refer anchor schedule	1.5	245kN	-	-
Marine 1 Barrier	Upslope Sacrificial Anchor, chainage 30m	1	Refer anchor schedule	1.5	360kN	-	-
	Lateral Sacrificial Anchor, chainage 88m	1	Refer anchor schedule	1.5	360kN	-	-
	Post tension Sacrificial Anchor, chainage 80m	1	Refer anchor schedule	1.5	360kN	-	-
Christmas Island Club Barrier	Upslope Sacrificial Anchor, chainage 25m	1	Refer anchor schedule	1.5	360kN	-	-
	Lateral Sacrificial Anchor, chainage 0m	1	Refer anchor schedule	1.5	360kN	-	-
	Post tension Sacrificial Anchor, chainage 48m	1	Refer anchor schedule	1.5	245kN	-	-
Boat Club Barrier	Upslope Sacrificial Anchor, chainage 20m	1	-	-	-	6.5	728
Marine 2 Barrier	Post Compression Sacrificial Anchor, chainage 66m	1	-	-	-	6.5	728
Marine 1 Barrier	Upslope Sacrificial Anchor, chainage 8m	1	-	-	-	6.5	728
	Post Compression Sacrificial Anchor, chainage 35m	1	-	-	-	6.5	728
Christmas Island Club Barrier	Post Tension Sacrificial Anchor, chainage 16m	1	-	-	-	6.5	728

### GROUND ANCHOR SCHEDULE - MARINE 1

ANCHOR LOCATION	ANCHOR TYPE	NUMBER OF ANCHORS	ANCHOR INCLINATION FROM HORIZONTAL	ULTIMATE LOAD PER ANCHOR	DRILLHOLE DIAMETER	ROCK EMBEDMENT			COLLUVIUM EMBEDMENT
						ESTIMATED SOIL DEPTH	MINIMUM BOND LENGTH IN SLIGHTLY WEATHERED ROCK	ESTIMATED TOTAL ANCHOR LENGTH	ESTIMATED ANCHOR LENGTH
			deg	kN	mm	m	m	m	m
Upslope Anchors	52/26 self drilling anchor	24	15	520	125	7	3.5	10.5	8
Lateral Anchors	L1: 52/26 self drilling anchor	2	45	600	125	14	4	18	9
	L2: 52/26 self drilling anchor	2	45	600	125	14	4	18	9
	L3: N/A	-	-	-	-	-	-	-	-
	L4: 52/26 self drilling anchor	2	45	600	125	14	4	18	9
Post Compression Anchors	52/26 self drilling anchor	72	90	480	125	9	5	14	6
Post Tension Anchors	52/26 self drilling anchor	24	45	380	125	8	2.5	10.5	6
Barrier Alignment Adjustment Anchors	40/16 self drilling anchor	2	15	310	85	7	3	10	6

### PULL-OUT TEST SCHEDULE - CHRISTMAS ISLAND CLUB DRAPED MESH

ANCHOR LOCATION	ANCHOR TYPE	NUMBER OF PULL-OUT TESTS	BONDED ANCHOR LENGTH	TEST LOAD
			m	kN
Christmas Island Club Draped Mesh	Crest Production Anchor	5	As Per Anchor Schedule	150

### GROUND ANCHOR SCHEDULE - CHRISTMAS ISLAND CLUB BARRIER

ANCHOR LOCATION	ANCHOR TYPE	NUMBER OF ANCHORS	ANCHOR INCLINATION FROM HORIZONTAL	ULTIMATE LOAD PER ANCHOR	DRILLHOLE DIAMETER	ROCK EMBEDMENT			COLLUVIUM EMBEDMENT
						ESTIMATED SOIL DEPTH	MINIMUM BOND LENGTH IN SLIGHTLY WEATHERED ROCK	ESTIMATED TOTAL ANCHOR LENGTH	ESTIMATED ANCHOR LENGTH
			deg	kN	mm	m	m	m	m
Upslope Anchors	52/26 self drilling anchor	20	15	500	125	4	3.5	7.5	8
Lateral Anchors	L1: 52/26 self drilling anchor	2	45	500	125	9	3.5	12.5	8
	L2: 52/26 self drilling anchor	2	45	500	125	9	3.5	12.5	8
	L3: 40/16 self drilling anchor	2	45	250	85	9	2.5	11.5	6
	L4: 40/16 self drilling anchor	2	45	250	85	9	2.5	11.5	6
Post Compression Anchors	52/26 self drilling anchor	60	90	300	125	5	4	9	6
Post Tension Anchors	40/16 self drilling anchor	20	45	320	85	5	3	8	6
Barrier Alignment Adjustment Anchors	52/26 self drilling anchor	1	15	220	85	4	2.5	6.5	6

### GROUND ANCHOR SCHEDULE - CHRISTMAS ISLAND CLUB DRAPED MESH

ANCHOR LOCATION	NUMBER OF ANCHORS	ANCHOR TYPE	DESIGN LOAD PER ANCHOR	DRILLHOLE DIAMETER	ANCHOR SPACING	MINIMUM BOND LENGTH IN SLIGHTLY WEATHERED ROCK	ANTICIPATED TOTAL ANCHOR LENGTH
							m
			kN	mm	m	m	m
Crest Anchors	63	T30/11 SDA	100	50	2.5	2	3
Toe Anchors*	8	T30/11 SDA	100	50	2.5	2	3

### FLEXIBLE BARRIER ANCHOR SCHEDULE - CONTINGENCY LENGTH

BARRIER	ANCHOR TYPE	CONTINGENCY LENGTH
		m
ANY BARRIER	40/16 SDA	466
	52/26 SDA	1923

### LONGITUDINAL CABLE SCHEDULE - CHRISTMAS ISLAND CLUB DRAPED MESH

CABLE LOCATION	CABLE TYPE	DRILLHOLE DIAMETER	STEEL GRADE
		mm	Mpa
Crest Cable	Steel Core	18	1690
Toe Cable	Steel Core	18	1690

40x 3m Crest Anchors + 2 x 3m Crest re-drills  
3 x Crest extensions at 4.5m  
4 x 3m Boulder anchors  
20 x 3m Toe Anchors

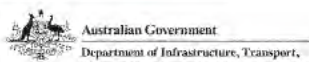
### NOTES

- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
- REFER TO DRAWINGS CI-GD-01 AND CI-GD-02 FOR ANCHOR DETAILS.
- DRAPED MESH MAY REQUIRE HAND-DRILLED TOE ANCHORS AT CERTAIN LOCATIONS TO ENSURE DETACHED BLOCKS DON'T ENCRoACH ON CONSTRUCTION ACCESS PATH. THE NUMBER, POSITION, BONDED LENGTH AND TYPE OF ANCHORS SHALL BE DETERMINED ON SITE BY THE SUPERVISING GEOTECHNICAL ENGINEER.
- ADOPTED ANCHOR EMBEDMENT MUST BE CONSISTENT WITH THE ADOPTED SACRIFICIAL ANCHOR TESTING FOR A GIVEN BARRIER. IF THE CONTRACTOR IS ONLY TARGETING EMBEDMENT IN COLLUVIUM, THE ROCK EMBEDMENT SACRIFICIAL ANCHORS AND TESTING ARE NOT REQUIRED.
- ANCHOR LENGTHS TO BE CONFIRMED BASED ON THE RESULTS OF THE SACRIFICIAL ANCHOR TESTS.

N.T.S

Project descope and hence not applicable.

Issue	Date	By	Child	Appd
C	13/10/20	RB	JG	EF
B	24/08/20	RB	JG	EF
D	8/10/21	RB	JG	EF
A	04/08/20	RB	JG	EF



Client: AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS

Job Title: FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN

Scale at A1: NTS



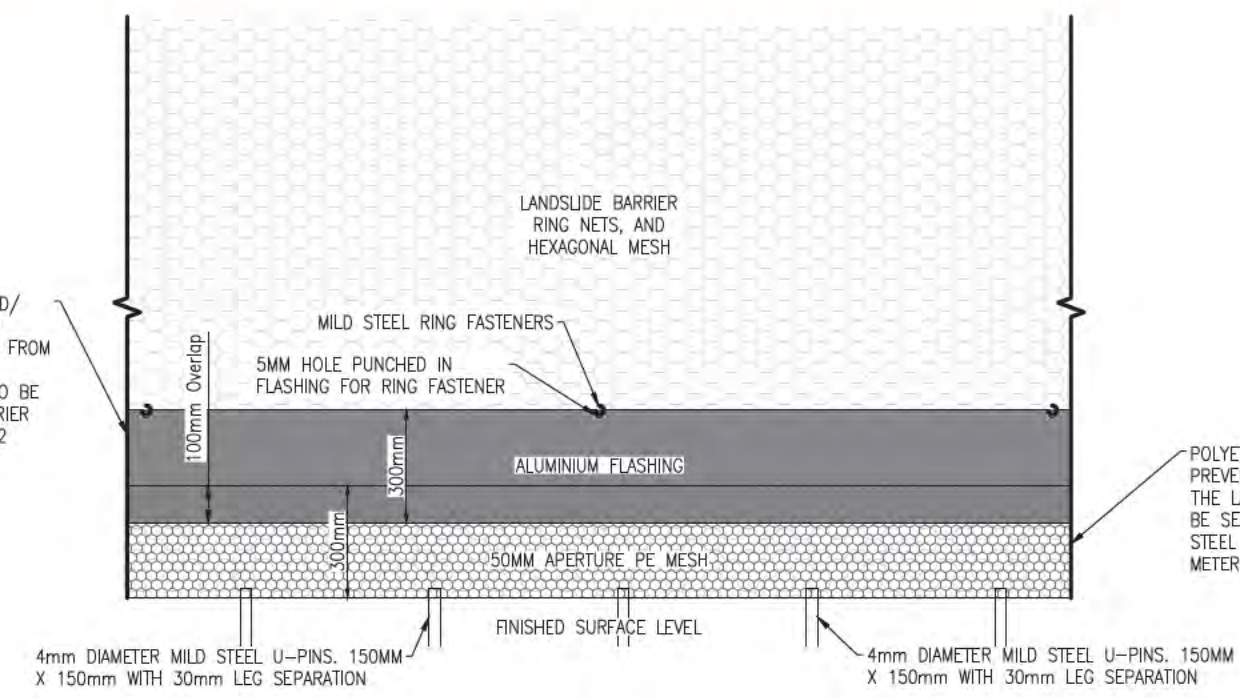
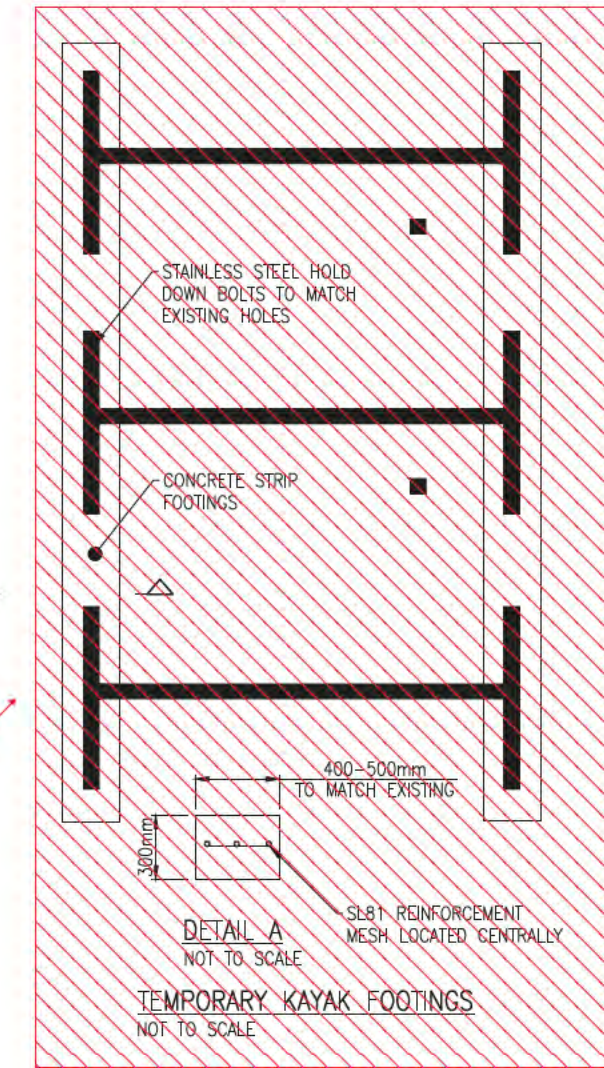
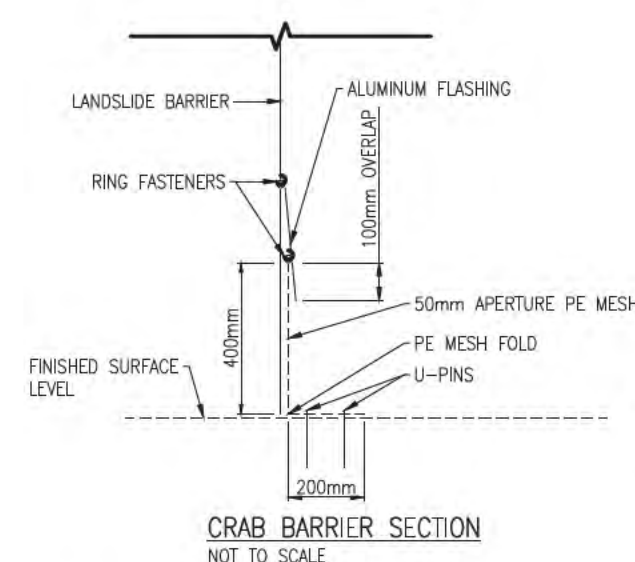
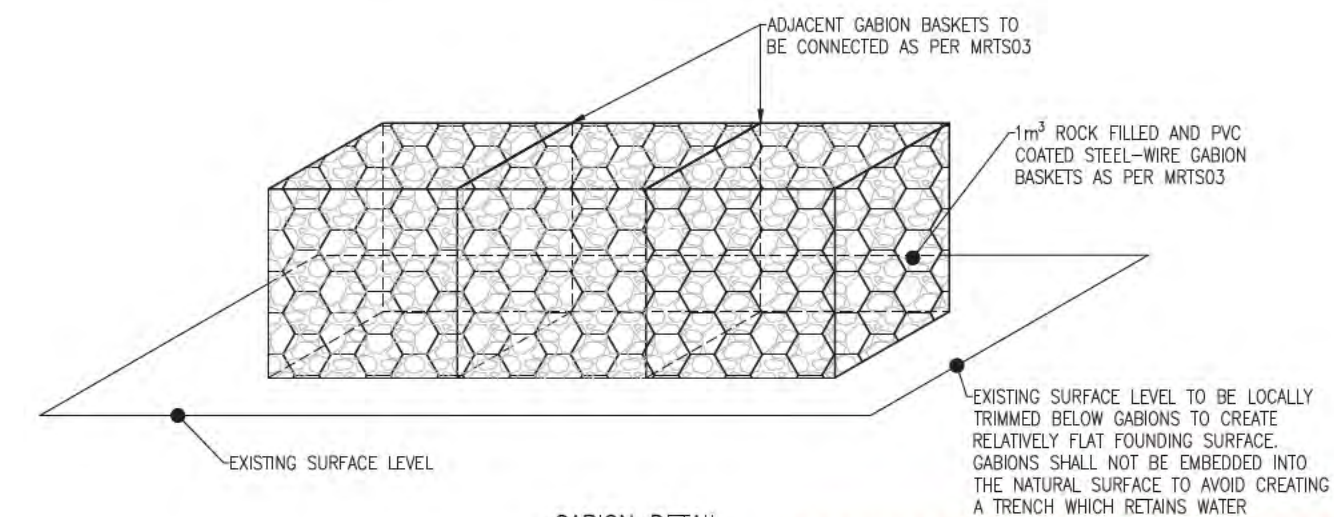
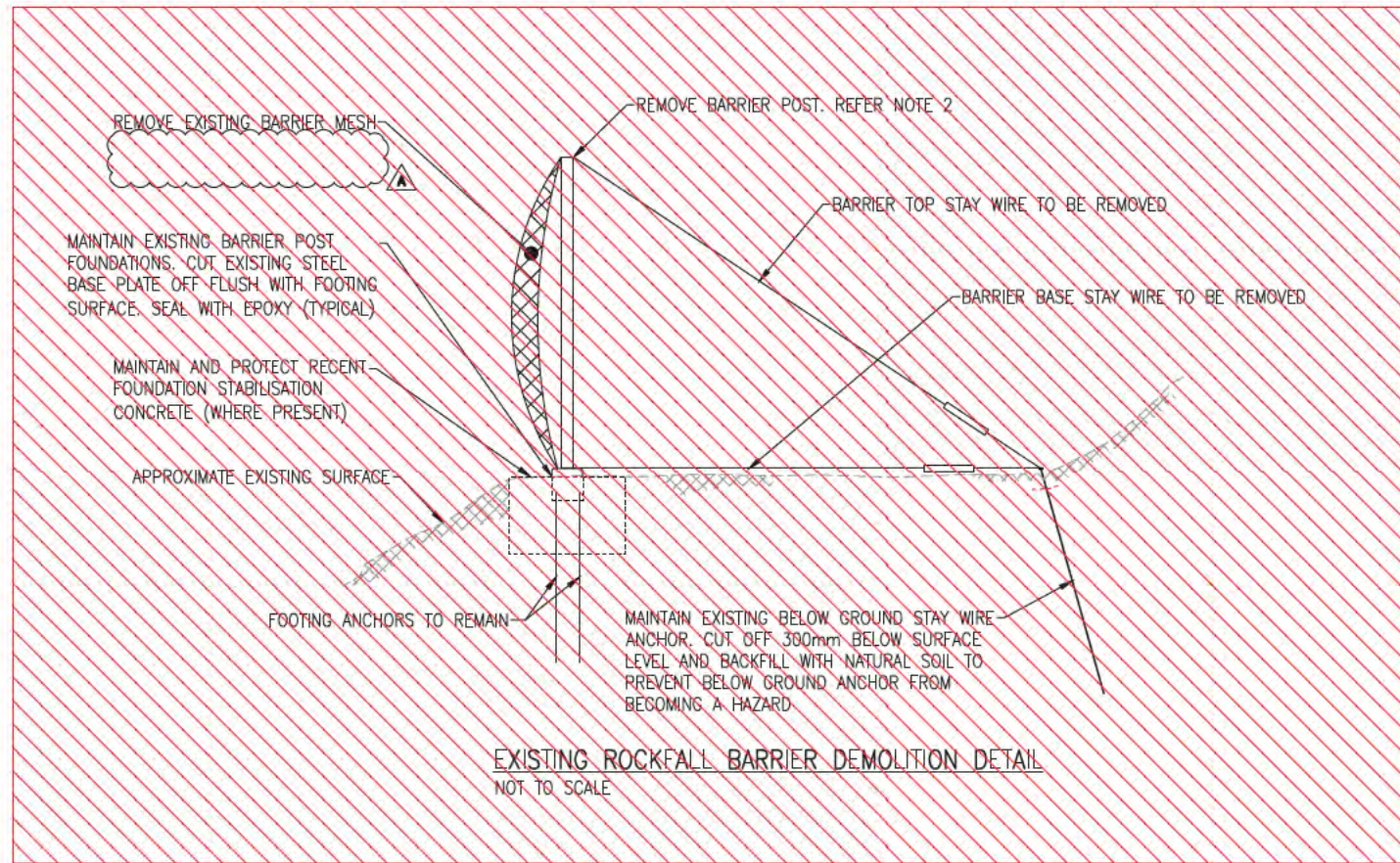
Level 4 108 Wickham Street  
Fortitude Valley QLD Australia 4026  
Tel +61(0)7320 9330 Fax +61(0)7320 9331  
www.arup.com



Drawing Title: LANDSLIDE MITIGATION TYPICAL DETAILS SHEET 3

Drawing Status: ISSUED FOR CONSTRUCTION

Job No: 268575-00 Drawing No: CI-GD-03 Issue: D



POLYETHYLENE (PE) MESH TO PREVENT CRABS BURROWING UNDER THE LANDSLIDE BARRIER. MESH TO BE SECURED AT THE TOP WITH 1N0 STEEL FASTENER EVERY 2 LINEAR METERS.

Kayak racks not relocated during the project as per Arup request email dated 20.10.20.

Due to descope client request retainage of existing fence materials

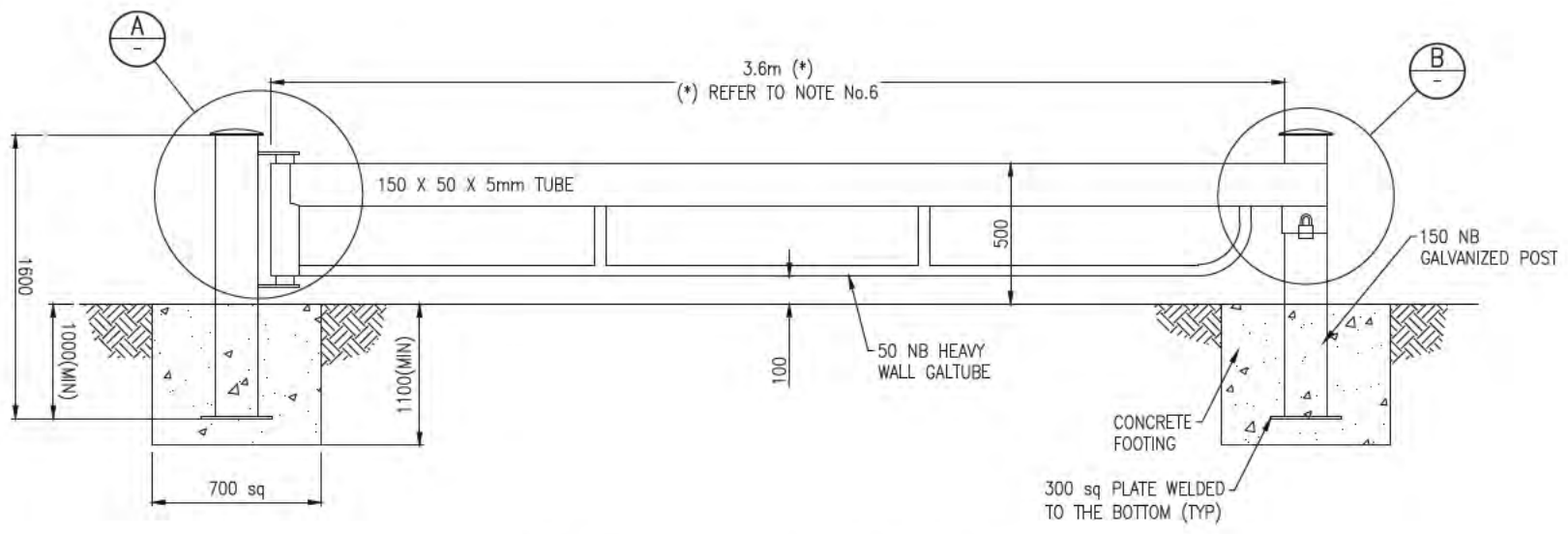
- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - CONTRACTOR SHALL REMOVE ALL ABOVE GROUND INFRASTRUCTURE UNLESS OTHERWISE NOTED. CONTRACTOR SHALL SHIP ALL REMOVED BARRIER MATERIAL BACK TO WESTERN AUSTRALIA (UNLESS OTHERWISE NOTED) FOR DISPOSAL AT APPROPRIATE FACILITY. CONTRACTOR TO PROVIDE EVIDENCE OF SHIPMENT AND CONFIRMATION OF APPROPRIATE DISPOSAL.

**ISSUED FOR CONSTRUCTION**

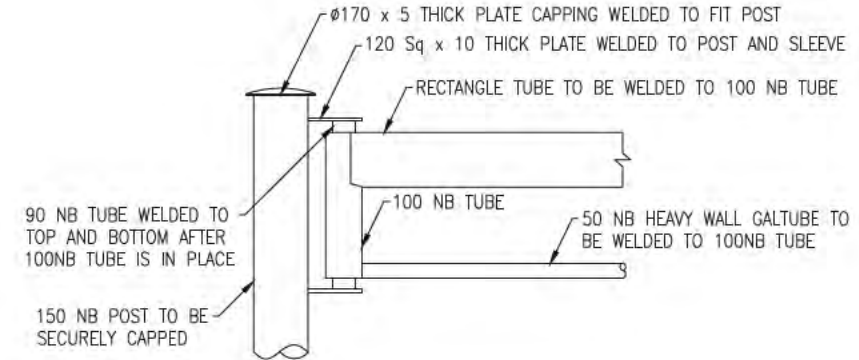
<p>Scales: N.T.S.</p>	<table border="1"> <tr> <td>Issue</td> <td>Date</td> <td>By</td> <td>CHKD</td> <td>Appd</td> </tr> <tr> <td>A</td> <td>04/08/20</td> <td>RB</td> <td>JG</td> <td>EF</td> </tr> </table>	Issue	Date	By	CHKD	Appd	A	04/08/20	RB	JG	EF	<p>Australian Government Department of Infrastructure, Transport, Regional Development and Communications</p>	<p>Client: AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS</p>	<p>Job Title: FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN</p>	<p>ARUP Level 4 108 Wickham Street Fortitude Valley QLD Australia 4006 Tel: +61 (0)7 320 9320 Fax: +61 (0)7 320 9321 www.arup.com</p>	<p>Drawing Title: LANDSLIDE MITIGATION TYPICAL DETAILS SHEET 4</p>
Issue	Date	By	CHKD	Appd												
A	04/08/20	RB	JG	EF												
<p>Design Model Version</p>	<p>ISSUED FOR CONSTRUCTION</p>	<p>Engineering Certification (CEng) Name: _____ Date: _____</p>	<p>Scale at A1: NTS</p>	<p>Discipline: _____</p>	<p>Member Firm Arup Pty Ltd ABN 18 000 969 185</p>	<p>Drawing Status: ISSUED FOR CONSTRUCTION</p>										
<p>Do not scale</p>	<p>Issue Date By CHKD Appd</p>	<p>Signature: _____ Date: _____</p>	<p>Discipline: _____</p>	<p>Job No: 268575-00</p>	<p>Member Firm Arup Pty Ltd ABN 18 000 969 185</p>	<p>Drawing No: CI-GD-04</p>										

**DRAWING COLOUR CODED - PRINT ALL COPIES IN COLOUR**

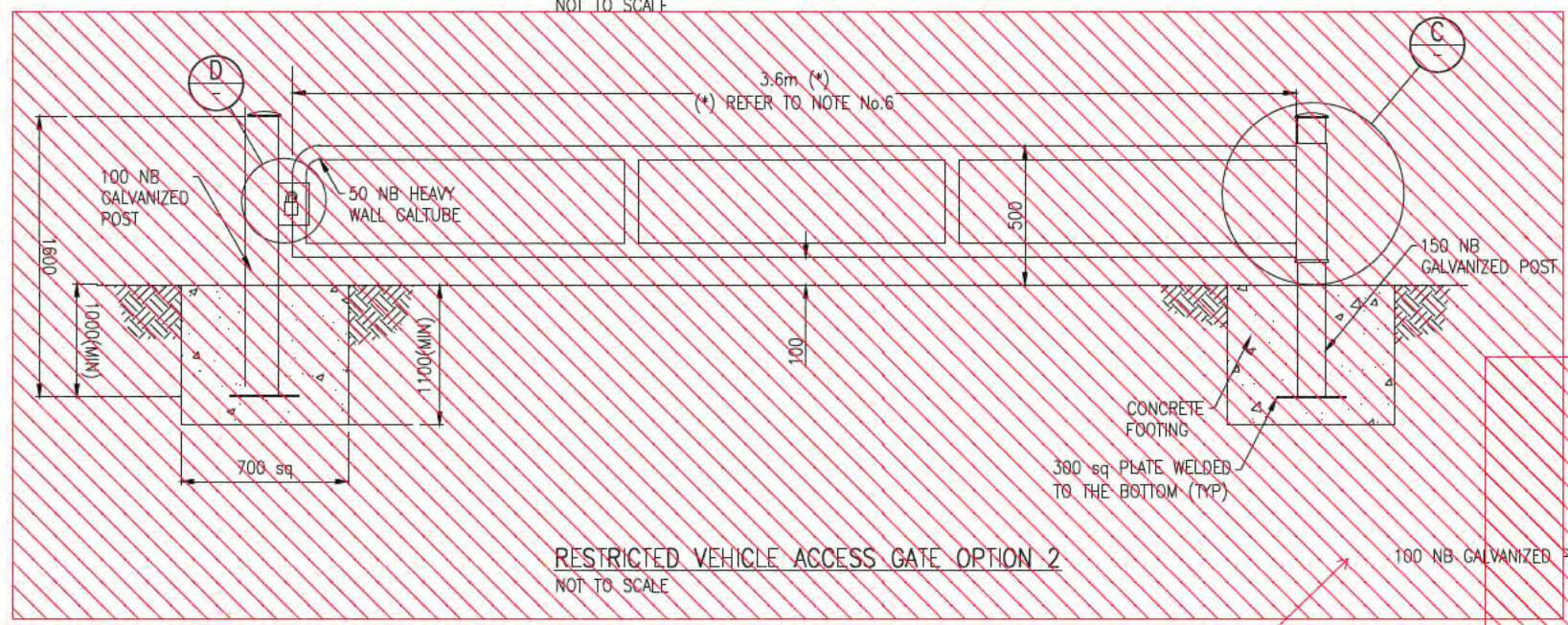
Released under the Freedom of Information Act 1982 by the Department of Infrastructure, Transport, Regional Development, Communications, Sport and the Arts



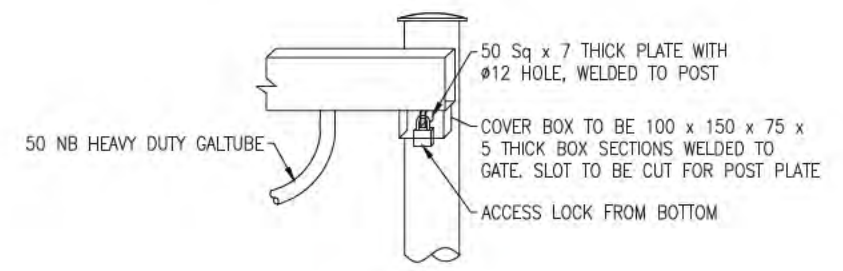
**RESTRICTED VEHICLE ACCESS GATE OPTION 1**  
NOT TO SCALE



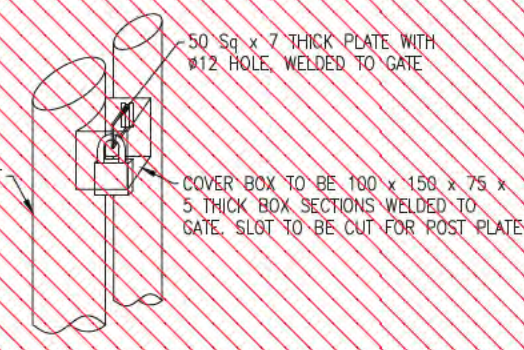
**DETAIL A**  
NOT TO SCALE



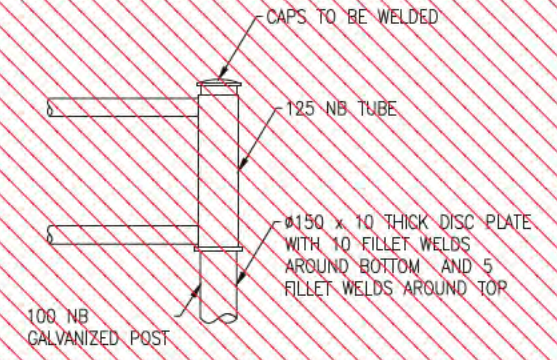
**RESTRICTED VEHICLE ACCESS GATE OPTION 2**  
NOT TO SCALE



**DETAIL B**  
NOT TO SCALE



**DETAIL D**  
NOT TO SCALE



**DETAIL C**  
NOT TO SCALE

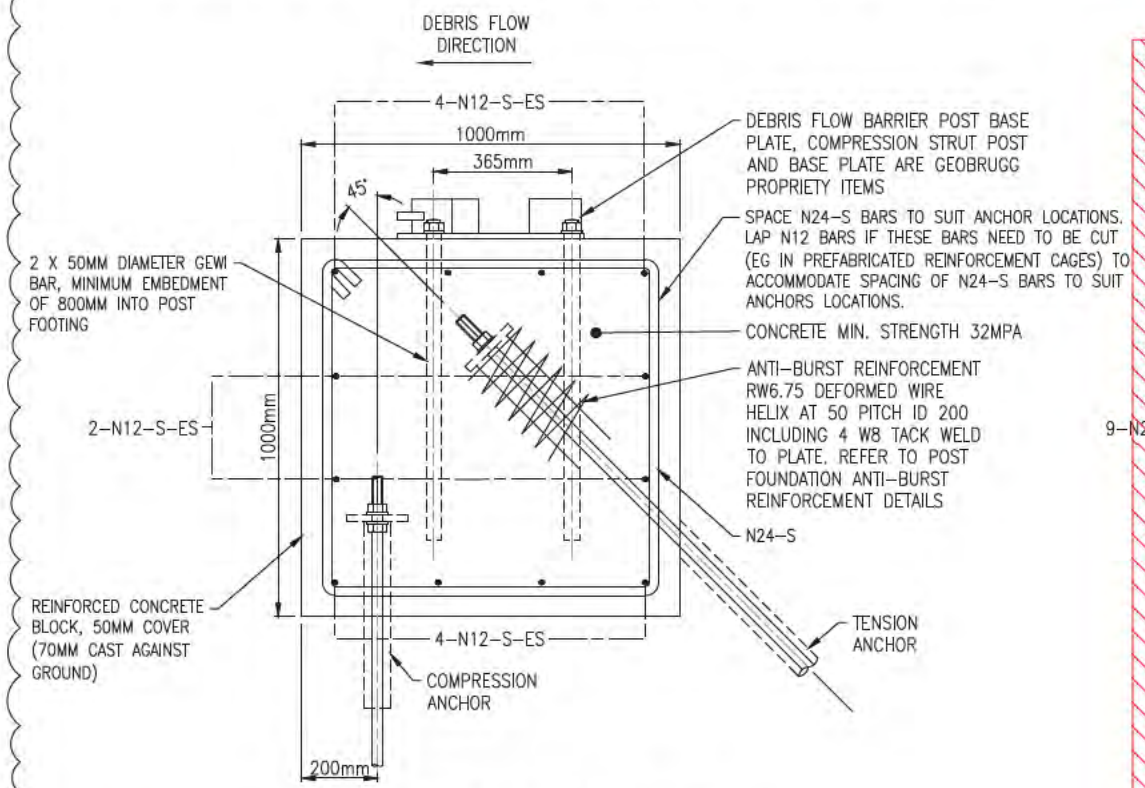
- NOTES**
1. ALL TUBING TO BE GALVANIZED STEEL
  2. ALL STEEL POSTS TO BE SECURELY CAPPED
  3. ALL WELDS TO BE POWER WIRE BRUSHED AND COLD GALVANIZED
  4. ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SHOWN
  5. MESH TO BE METRIC MESH 46G5 AND GALVANIZED FINISHED COMPLETE WITH FITTINGS
  6. A 3.9m GATE SHALL ONLY BE INSTALLED WHEN THE INTERNAL VEHICLE TRACK DOES NOT RUN PERPENDICULAR TO THE GATE LOCATION, ALL GATES WITH WIDTHS LARGER THAN 3.9m SHALL ONLY BE CONSIDERED IN EXCEPTIONAL CIRCUMSTANCES AND TECHNICAL SPECIFICATIONS WILL REQUIRE APPROVAL PRIOR TO INSTALLATION
  7. CONCRETE FOOTINGS TO BE GRADE N32 TO AS 1397
  8. ALL GALVANIZED STEEL TO MEET AS/NZS 4792 FOR HOT-DIP GALVANIZED (ZINC) COATING ON FABRICATED FERROUS ARTICLES
  9. ALL POSTS WITH FOOTINGS SHALL HAVE A WALL THICKNESS OF 5mm
  10. COVERED LOCKBOX OF OPTION 1 & 2 ONLY OPEN AT BASE
  11. THESE DETAILS HAVE BEEN TAKEN FROM THE CITY OF WANNEROO INFRASTRUCTURE, STANDARD DRAWING NUMBER TS01-14-0, APPROVED 16/2/2015.

Option 2 not used

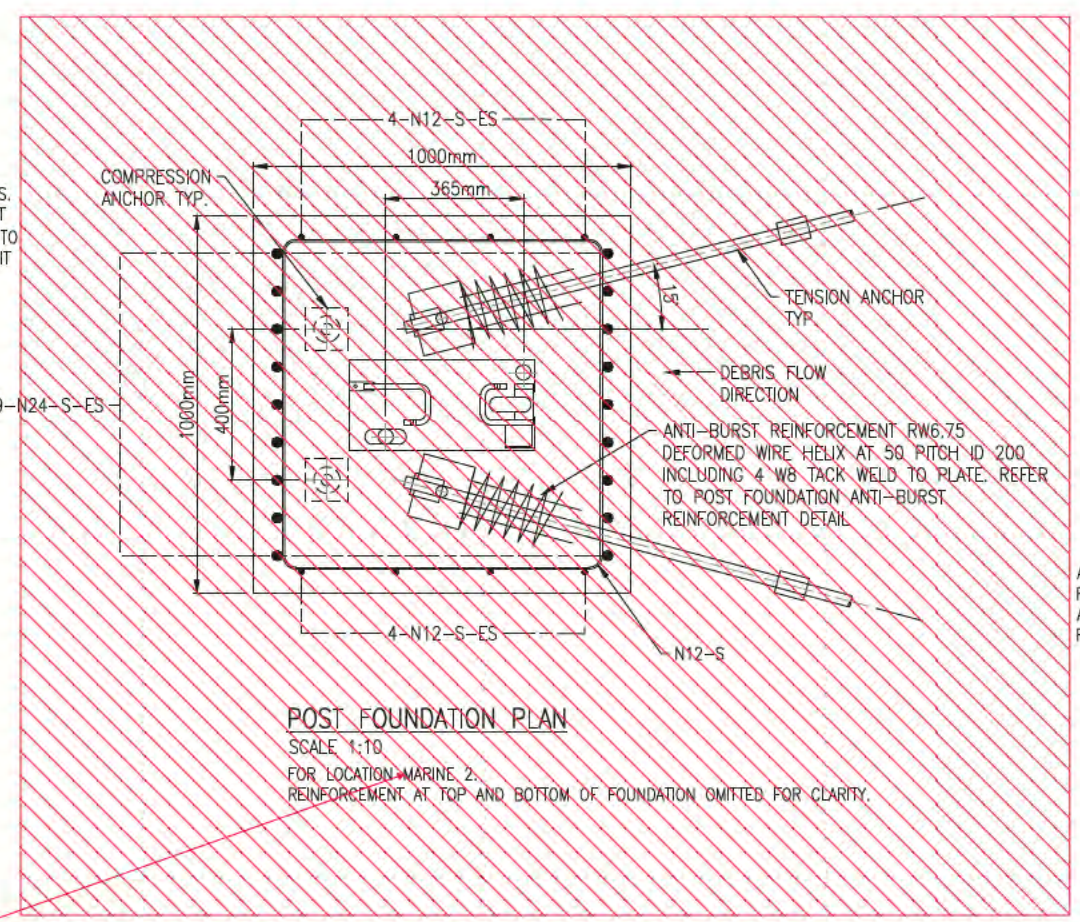
- NOTES**
1. REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.

**ISSUED FOR CONSTRUCTION**

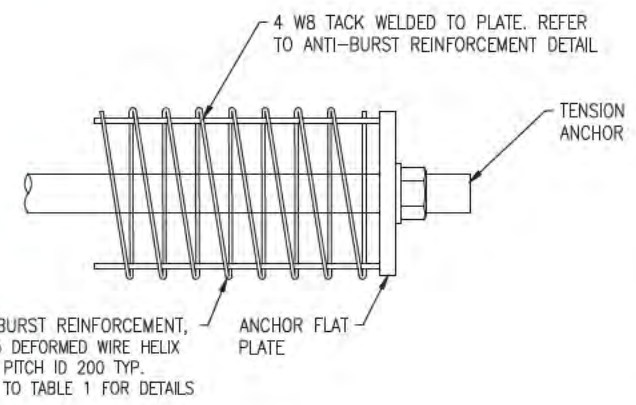
<p>Scales: N.T.S.</p>	<table border="1"> <tr> <td>Issue</td> <td>Date</td> <td>By</td> <td>CHKD</td> <td>Appd</td> </tr> <tr> <td>A</td> <td>04/08/20</td> <td>RB</td> <td>JG</td> <td>EF</td> </tr> </table>	Issue	Date	By	CHKD	Appd	A	04/08/20	RB	JG	EF	<p>Australian Government Department of Infrastructure, Transport, Regional Development and Communications</p>	<p>Client: AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS</p>	<p>Job Title: FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN</p>	<p>ARUP Level 4 108 Wickham Street Fortitude Valley QLD Australia 4006 Tel: +61 (0)7 320 9320 Fax: +61 (0)7 320 9321 www.arup.com</p>	<p>Drawing Title: LANDSLIDE MITIGATION TYPICAL DETAILS SHEET 5</p>
Issue	Date	By	CHKD	Appd												
A	04/08/20	RB	JG	EF												
<p>Design Model Version</p>	<table border="1"> <tr> <td>Issue</td> <td>Date</td> <td>By</td> <td>CHKD</td> <td>Appd</td> </tr> <tr> <td>A</td> <td>04/08/20</td> <td>RB</td> <td>JG</td> <td>EF</td> </tr> </table>	Issue	Date	By	CHKD	Appd	A	04/08/20	RB	JG	EF	<p>Engineering Certification (CEng) Name: _____ Date: _____ Signature: _____</p>	<p>Scale at A1: NTS Discipline: _____</p>	<p>Member Firm ARUP Pty Ltd ABN 18 000 960 185</p>	<p>Drawing Status: <b>ISSUED FOR CONSTRUCTION</b></p>	<p>Job No: 268575-00 Drawing No: CI-GD-05 Issue: A</p>
Issue	Date	By	CHKD	Appd												
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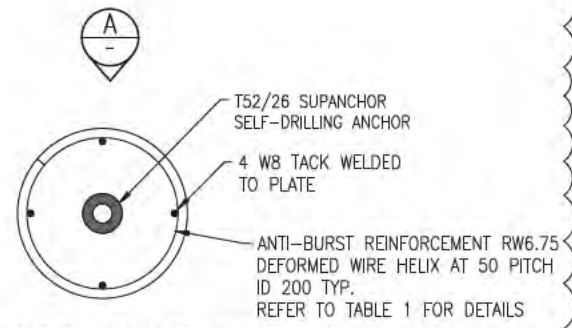
**POST FOUNDATION ELEVATION**  
SCALE 1:10



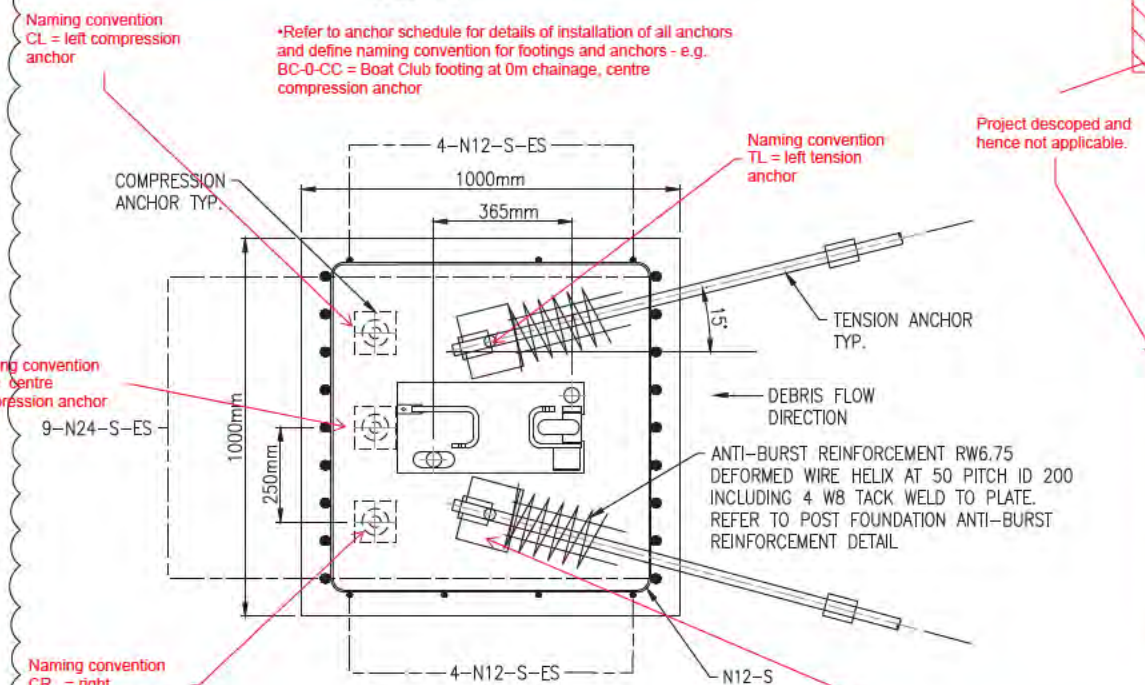
**POST FOUNDATION PLAN**  
SCALE 1:10  
FOR LOCATION MARINE 2.  
REINFORCEMENT AT TOP AND BOTTOM OF FOUNDATION OMITTED FOR CLARITY.



**VIEW A**  
SCALE 1:5



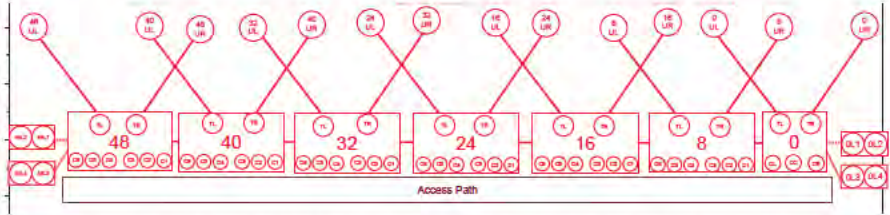
**POST FOUNDATION ANTI-BURST REINFORCEMENT DETAILS**  
SCALE 1:5



**POST FOUNDATION PLAN**  
SCALE 1:10  
FOR LOCATIONS BOAT CLUB - Footing BC80 only - Rock Embedment  
REINFORCEMENT AT TOP AND BOTTOM OF FOUNDATION OMITTED FOR CLARITY.

**TABLE 1: ANTI-BURST REINFORCEMENT - HELIX DETAILS**

LOCATION	HELIX	PITCH (mm)	INNER DIAMETER ID (mm)	No. OF TURNS
BOAT CLUB BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	10
MARINE 2 BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	8
MARINE 1 BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	10
CHRISTMAS ISLAND CLUB BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	8
COMPRESSION STRUT POST MARINE 2 BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	8
END POST MARINE 2 BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	10



**NOTES**

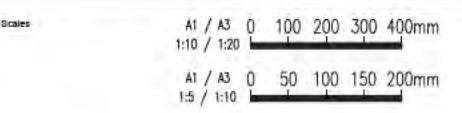
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
- REFER TO DRAWINGS CI-GD-01 AND CI-GD-02 FOR ANCHOR DETAILS.
- REFER TO DRAWING CI-CI-01 FOR PROPOSED BARRIER FOUNDATION SETOUTS.
- ES DENOTES EVENLY SPACED.
- WHERE ALL GROUND ANCHORS WITHIN A FOUNDATION PLAN ARE INSTALLED WITH ROCK EMBEDMENT AS PER DRAWING CI-GD-03 (OR CI-GD-08 FOR MARINE 2 BARRIER END POST AND COMPRESSION STRUT AT CH 111.16 AND CH 114), DETAILS ON DRAWING CI-GD-06 AND CI-GD-07 APPLY FOR THE FOUNDATION.
- WHERE GROUND ANCHORS ARE INSTALLED WITH ONLY COLLUVIUM EMBEDMENT AS PER DRAWING CI-GD-03 (OR CI-GD-08 FOR MARINE 2 BARRIER END POST AND COMPRESSION STRUT AT CH 111.16 AND CH 114), REFER TO THE FOUNDATION DETAILS SHOWN ON CI-GD-12 AND CI-GD-13.

Naming convention  
CL = left compression anchor  
\*Refer to anchor schedule for details of installation of all anchors and define naming convention for footings and anchors - e.g. BC-0-CC = Boat Club footing at 0m chainage, centre compression anchor

Naming convention  
TL = left tension anchor  
Project descope and hence not applicable.

Naming convention  
CC = centre compression anchor

Naming convention  
CR = right compression anchor  
Naming convention  
TR = right tension anchor



Issue	Date	By	Chkd	Appd
C	10/09/21	ML	JG	EF
Revised As Clouded				
B	13/10/20	RB	JG	EF
Marine 2 Compression Strut				
A	04/08/20	RB	JG	EF
ISSUED FOR CONSTRUCTION				

Issue	Date	By	Chkd	Appd
C	10/09/21	ML	JG	EF
Revised As Clouded				
B	13/10/20	RB	JG	EF
Marine 2 Compression Strut				
A	04/08/20	RB	JG	EF
ISSUED FOR CONSTRUCTION				

Australian Government  
Department of Infrastructure, Transport,  
Regional Development and Communications

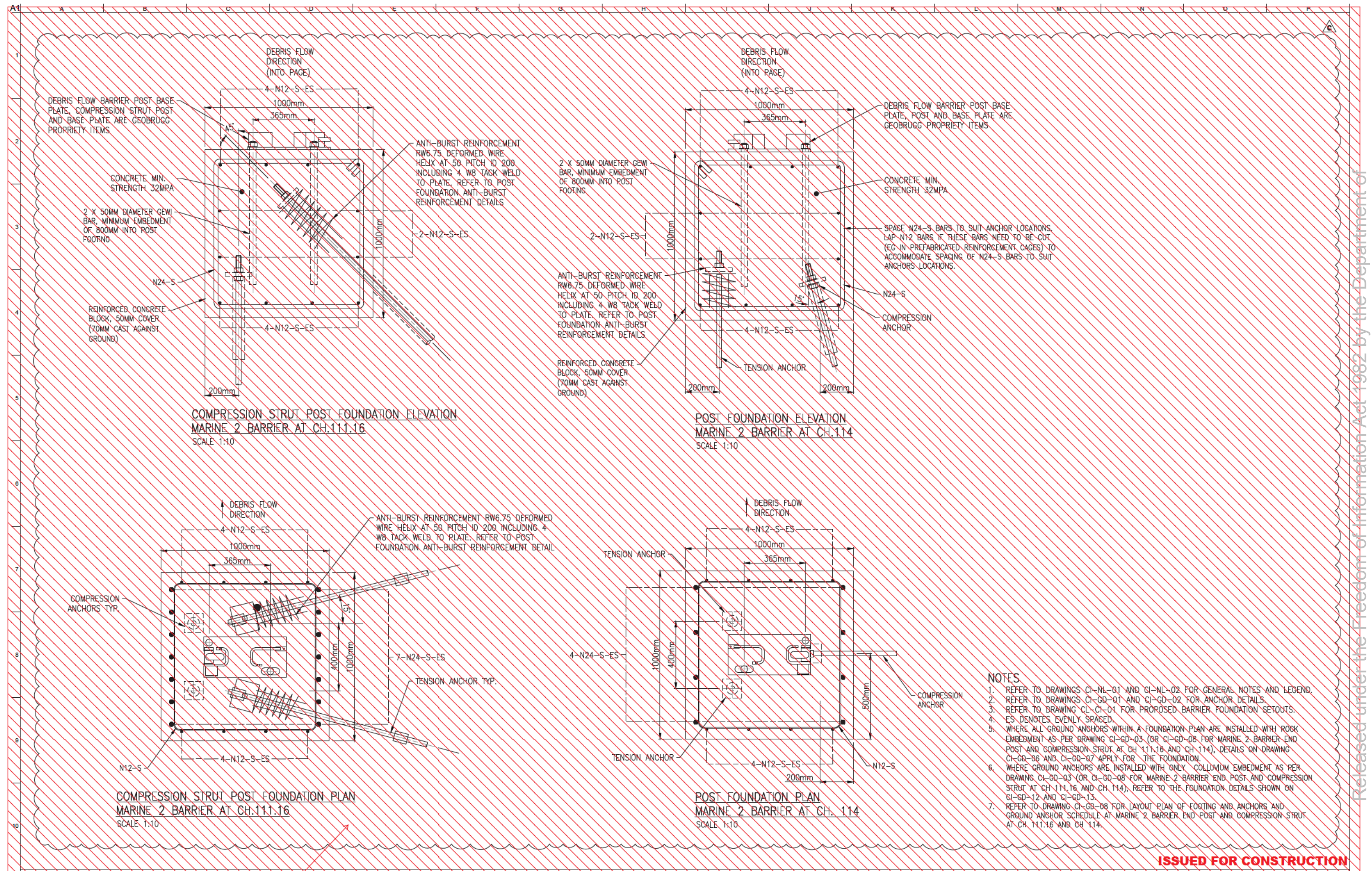
Client  
AUSTRALIAN GOVERNMENT DPT  
OF INFRASTRUCTURE, TRANSPORT,  
REGIONAL DEVELOPMENT  
AND COMMUNICATIONS

Job Title  
FLYING FISH COVE  
CHRISTMAS ISLAND  
LANDSLIDE MITIGATION  
DETAILED DESIGN

**ARUP**  
Level 4 108 Wickham Street  
Fortitude Valley QLD Australia 4006  
Tel +61(0)7320 9320 Fax +61(0)7320 9321  
www.arup.com

CONSULT AUSTRALIA  
Member Firm  
Aus Pty Ltd  
ABN 18 000 960 185

Drawing Title  
LANDSLIDE MITIGATION  
POST FOOTING CONCRETE DETS  
SHEET 6  
Drawing Status  
**ISSUED FOR CONSTRUCTION**  
Job No  
268575-00  
Drawing No  
CI-GD-06  
Issue  
D



**ISSUED FOR CONSTRUCTION**

Scales: A1 / A3 0 100 200 300 400mm  
1:10 / 1:20

Project descoped and hence not applicable.

Issue	Date	By	Child	Appd

C	19/10/21	MA	JG	EF
Revised As Clouded				
B	10/09/21	ML	JG	EF
Revised As Clouded				
A	13/10/20	RB	JG	EF
ISSUED FOR CONSTRUCTION				
Issue	Date	By	Child	Appd

Australian Government  
Department of Infrastructure, Transport, Regional Development and Communications

Client: AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS

Engineering Certification (CEng)  
Name: \_\_\_\_\_ Date: \_\_\_\_\_  
Signature: \_\_\_\_\_

Job Title: FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN

Scale at A1: AS SHOWN

Discipline: \_\_\_\_\_

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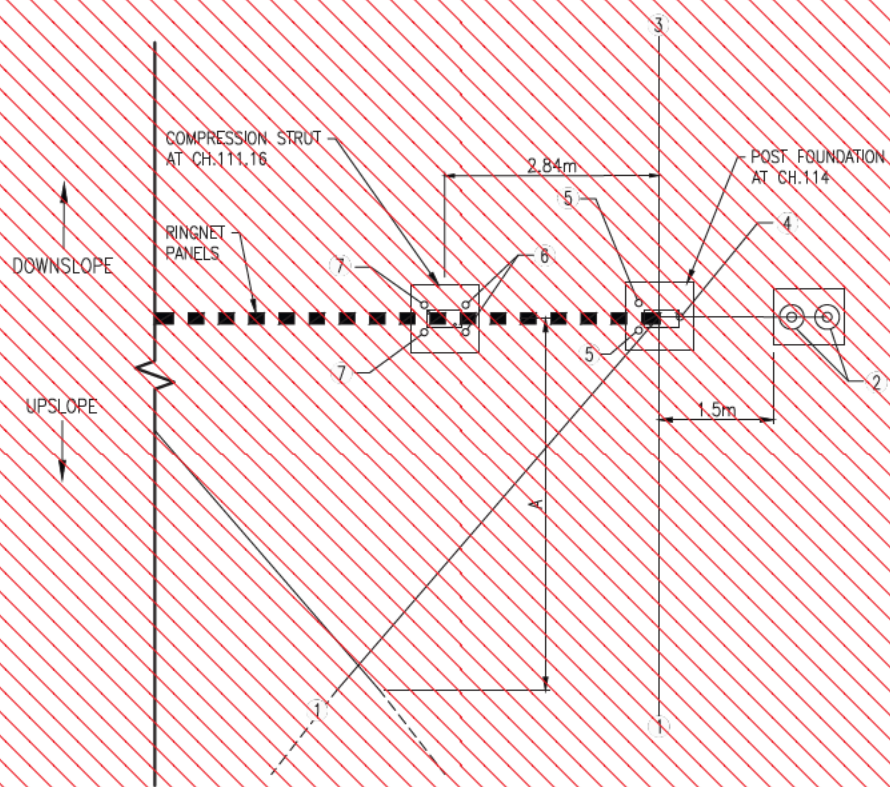
CONSULT AUSTRALIA  
Member Firm  
Aus Pty Ltd  
ABN 18 000 968 165

Drawing Title: LANDSLIDE MITIGATION POST FOOTING CONCRETE DETAILS - SHEET 7

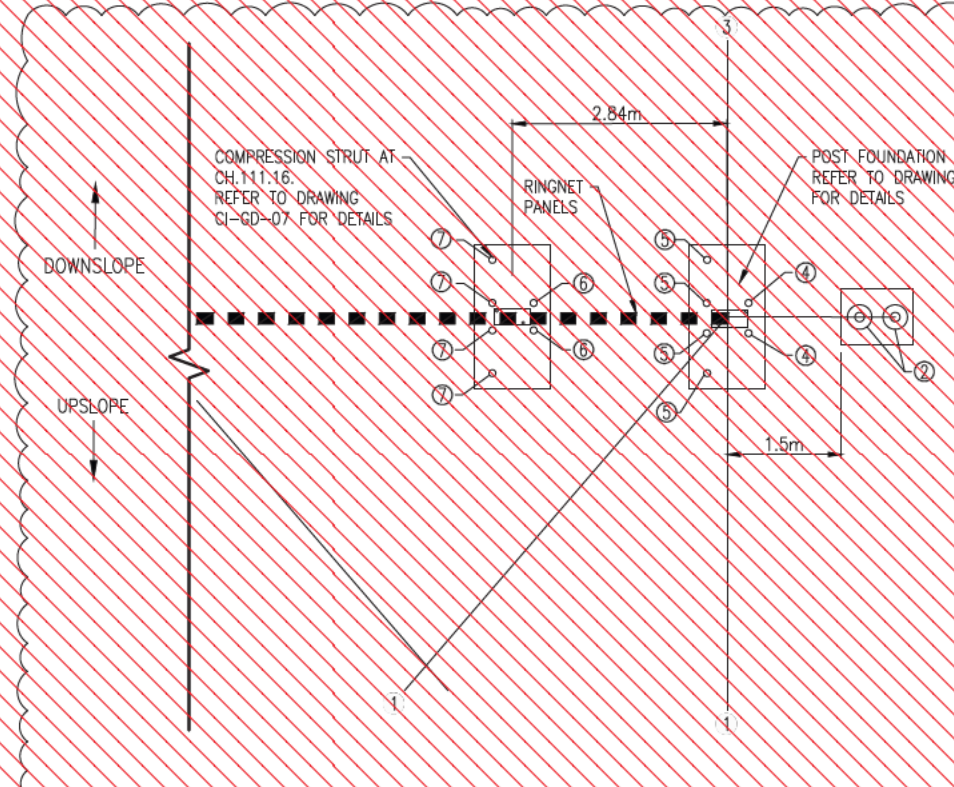
Drawing Status: **ISSUED FOR CONSTRUCTION**

Job No: 268575-00  
Drawing No: CI-GD-07  
Issue: C

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MARINE 2 BARRIER END POST AND COMPRESSION STRUT FOUNDATION LAYOUT PLAN (IF ALL GROUND ANCHORS HAVE ROCK EMBEDMENT) SCALE 1:50



MARINE 2 BARRIER END POST AND COMPRESSION STRUT FOUNDATION LAYOUT PLAN (IF GROUND ANCHORS ONLY HAVE COLLUVIUM EMBEDMENT) SCALE 1:50

ANCHOR SETOUT DETAILS FOR MARINE 2 BARRIER END POST AND COMPRESSION STRUT AT CH 111.16 and CH 114

Anchor Location	Schematic Position	Anchor Type	Number of anchors	Anchor inclination from horizontal deg	Indicative Ultimate load per anchor kN	Drillhole diameter mm	Rock Embedment			Colluvium Embedment
							Estimated soil depth (m)	Minimum bond length in slightly weathered rock (m)	Estimated total anchor length (m)	Estimated anchor length (m)
End post Upslope Anchors	1	52/26 self drilling anchor	2	15	350	125	8	2.5	10.5	6
End Post Lateral Anchors	2	40/16 self drilling anchor	2	45	300	85	14	3	17	6
End Post Downslope Anchor	3	40/16 self drilling anchor	1	45	300	85	14	3	17	6
End Post Compression Anchor	4	40/16 self drilling anchor	2	15	125	85	8	2.5	10.5	6
End Post Tension Anchors	5	52/26 self drilling anchor	4	90	285	125	8	4	12	6
Compression Strut Tension Anchors	6	52/26 self drilling anchor	2	45	445	125	14	3	17	7
Compression Strut Compression Anchors	7	52/26 self drilling anchor	4	90	385	125	8	5	13	6

\* ANCHOR NUMBER AND LOADING BASED ON THE COLLUVIUM EMBEDMENT ANCHOR ARRANGEMENT

- NOTES**
- THIS DRAWING IS TO BE READ IN CONJUNCTION WITH DRAWINGS CI-GD-07 AND CI-GD-13.
  - REFER TO DRAWING CI-CI-01 FOR PROPOSED BARRIER FOUNDATION SETOUTS.

**ISSUED FOR CONSTRUCTION**

Scale: A1 / A3 0 1000 2000mm  
1:50 / 1:100

Project descoped and hence not applicable.

Issue	Date	By	Chkd	Appd

	19/10/21	MA	JG	EF



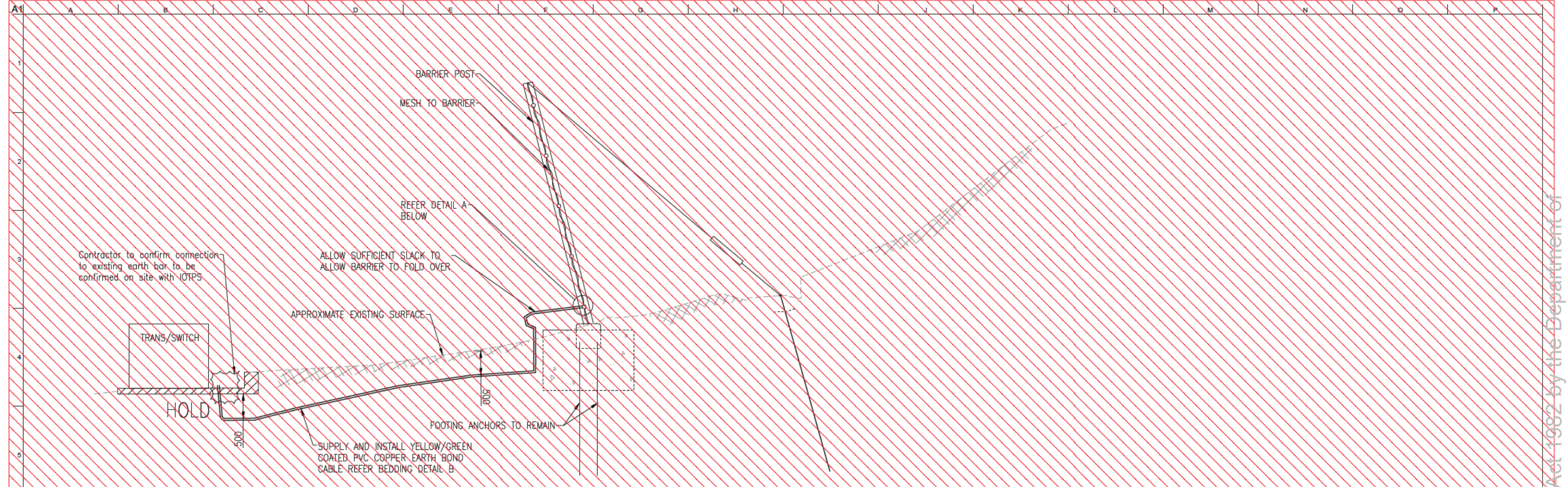
**AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS**  
Engineering Certification (CEng)  
Name: \_\_\_\_\_ Date: \_\_\_\_\_  
Signature: \_\_\_\_\_

**FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN**  
Scale at A1 AS SHOWN  
Discipline

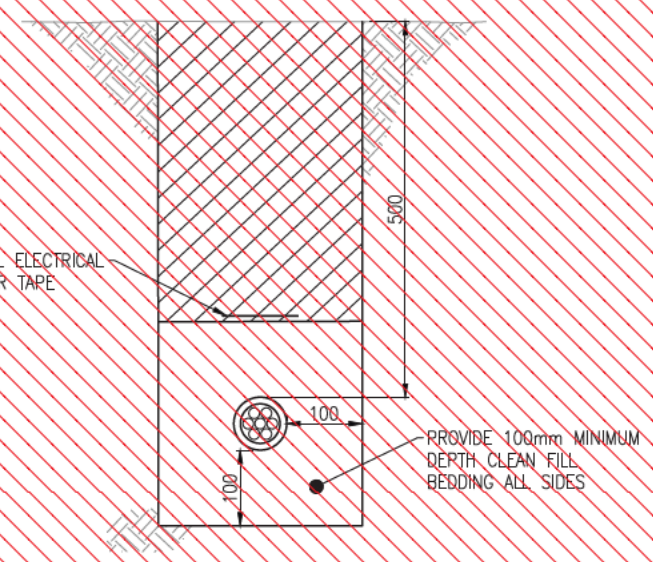


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Member Firm  
Avp Pty Ltd  
ABN 18 000 968 165

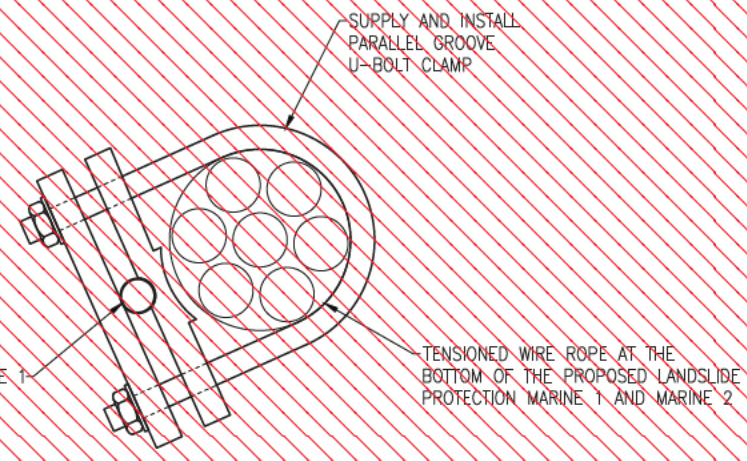
**LANDSLIDE MITIGATION TYPICAL DETAILS SHEET 8**  
Drawing Status  
**ISSUED FOR CONSTRUCTION**  
Job No: 268575-00  
Drawing No: CI-GD-08  
Issue: C



SECTIONAL VIEW - FACING NORTH EAST ALONG BARRIER TOWARDS CLUB  
NOT TO SCALE



DETAIL B: BEDDING DETAIL  
NOT TO SCALE



DETAIL A: CONNECTION DETAIL  
NOT TO SCALE

**NOTE**

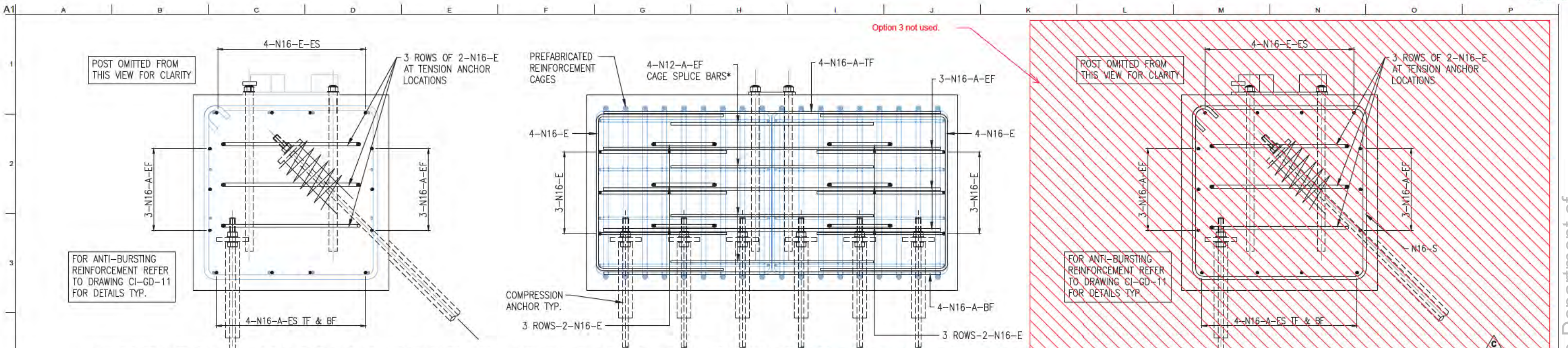
1. SUPPLY AND INSTALL YELLOW/GREEN PVC COATED COPPER EARTH BOND CABLE, CABLE CROSS SECTIONAL AREA TO BE CONFIRMED ON SITE AND MUST BE EQUAL TO OR GREATER THAN THE CROSS SECTIONAL AREA OF EXISTING EARTHING CABLES USED AT THE SUBSTATION. STRIP PVC SHEATH BACK TO ALLOW METAL ON METAL CONTACT WITH THE CLAMP.
2. ONE EQUIPOTENTIAL BOND CABLE CONNECTION TO BE PROVIDED TO THE MARINE 1 AND 2 BARRIER RESPECTIVELY. ALIGNMENT TO BE CONFIRMED ON SITE POST SERVICE LOCATION AND POT HOLING.
3. THE U BOLT CLAMP TO BE SIZED TO SUIT THE DIAMETER OF THE WIRE ROPE AT THE BOTTOM OF THE PROPOSED BARRIERS.

**ISSUED FOR CONSTRUCTION**

<p>Scales <b>N.T.S</b></p> <p>Project descoped and hence not applicable.</p>	<table border="1"> <tr> <td>Issue</td> <td>Date</td> <td>By</td> <td>Chkd</td> <td>Appd</td> </tr> <tr> <td> </td> <td> </td> <td> </td> <td> </td> <td> </td> </tr> </table>	Issue	Date	By	Chkd	Appd						<table border="1"> <tr> <td>Issue</td> <td>Date</td> <td>By</td> <td>Chkd</td> <td>Appd</td> </tr> <tr> <td>A</td> <td>8/11/20</td> <td>RB</td> <td>DS</td> <td>EF</td> </tr> </table> <p>Earth Bond Connection Detail</p>	Issue	Date	By	Chkd	Appd	A	8/11/20	RB	DS	EF	<p>Australian Government Department of Infrastructure, Transport, Regional Development and Communications</p>	<p>Client <b>AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS</b></p> <p>Engineering Certification (CEng) Name: _____ Date: _____ Signature: _____</p>	<p>Job Title <b>FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN</b></p> <p>Scale at A1 NTS</p> <p>Discipline</p>	<p>Level 4 108 Wickham Street Fortitude Valley QLD Australia 4006 Tel +61(0)7320 9320 Fax +61(0)7320 9321 www.arup.com</p>	<p>Member Firm Aus Pty Ltd ABN 18 000 968 165</p>	<p>Drawing Title <b>LANDSLIDE MITIGATION TYPICAL DETAILS SHEET 9</b></p> <p>Drawing Status <b>ISSUED FOR CONSTRUCTION</b></p> <p>Job No <b>268575-00</b></p> <p>Drawing No <b>CI-GD-09</b></p> <p>Issue <b>A</b></p>
Issue	Date	By	Chkd	Appd																								
Issue	Date	By	Chkd	Appd																								
A	8/11/20	RB	DS	EF																								

**DRAWING COLOUR CODED - PRINT ALL COPIES IN COLOUR**

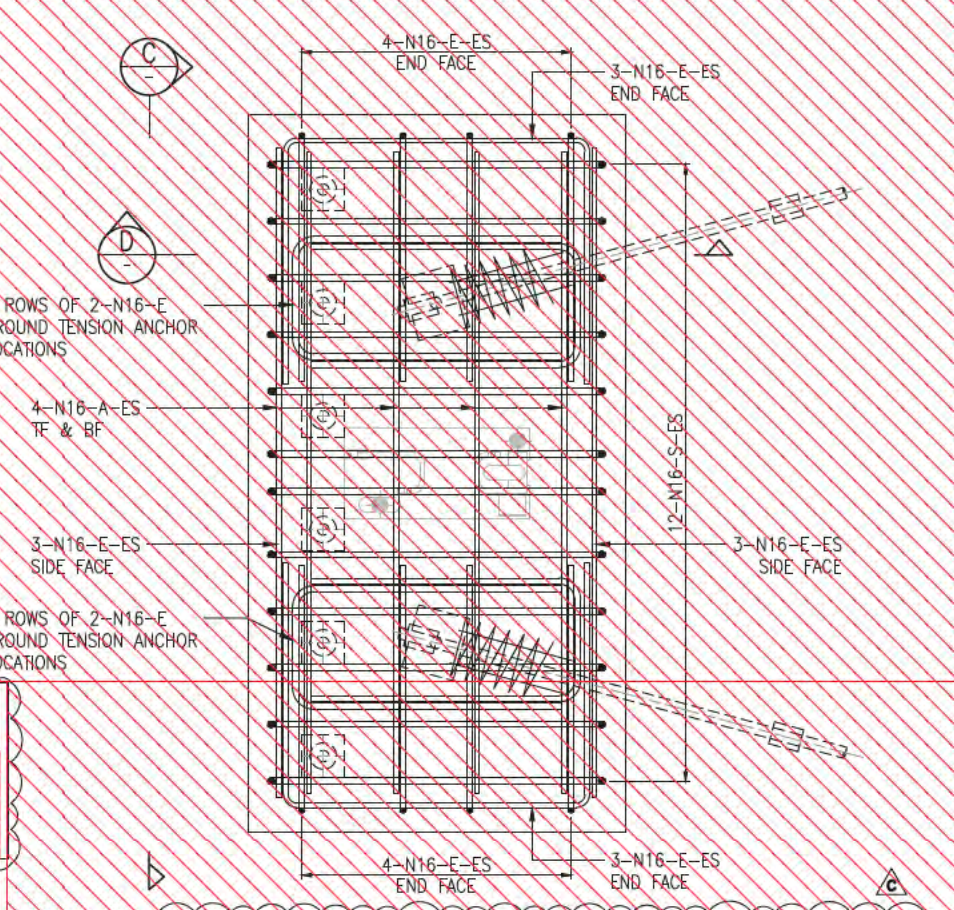
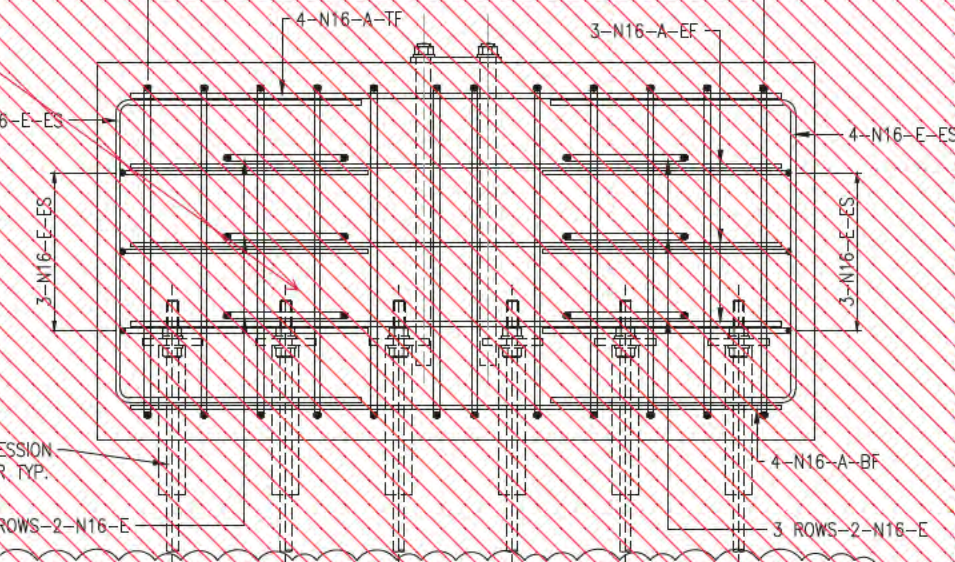
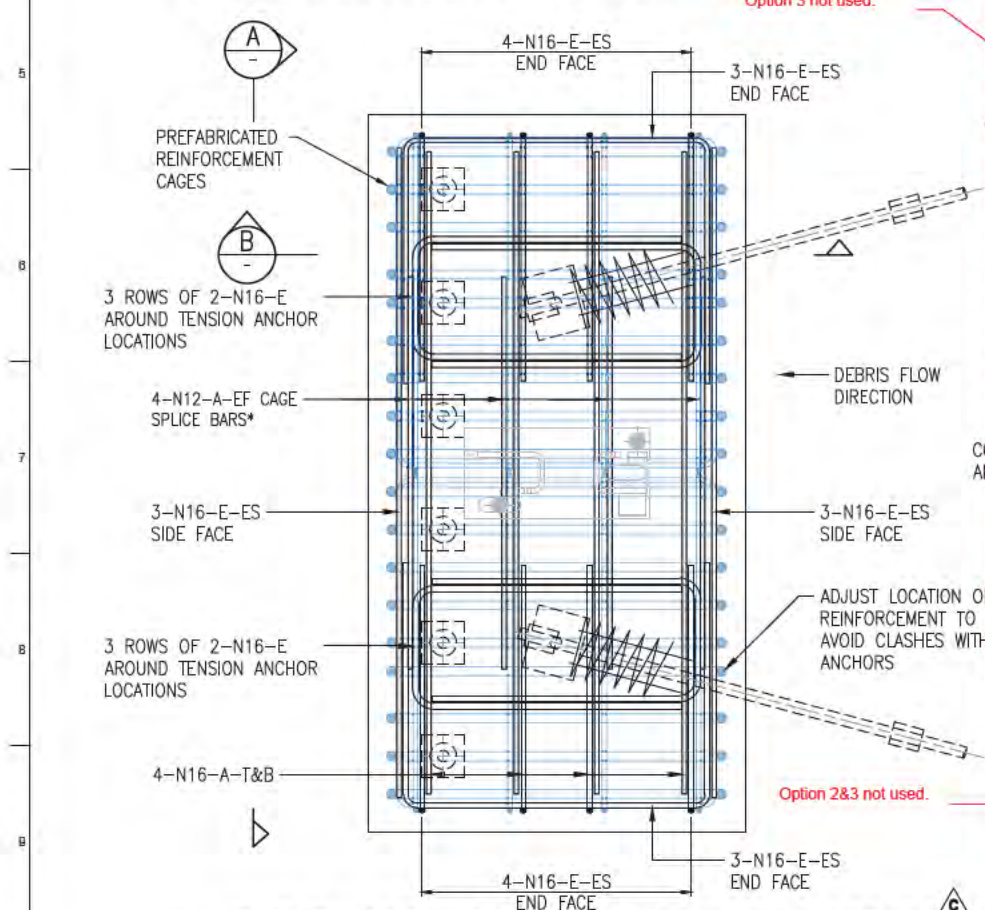
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**REINFORCEMENT OPTION 1** (REFER NOTE 'ALTERNATIVE REINFORCEMENT OPTIONS')  
**SECTION B**  
 SCALE 1:10  
 Reinforcement used for Footings BCB8, 16, 24, 32, 40 & 48.

**REINFORCEMENT OPTION 1** (REFER NOTE 'ALTERNATIVE REINFORCEMENT OPTIONS')  
**ELEVATION A**  
 TENSION ANCHORS OMITTED FROM VIEW FOR CLARITY  
 SCALE 1:10  
 Reinforcement used for Footings BCB8, 16, 24, 32, 40 & 48.

**REINFORCEMENT OPTION 3** (REFER NOTE 'ALTERNATIVE REINFORCEMENT OPTIONS')  
**SECTION D**  
 SCALE 1:10



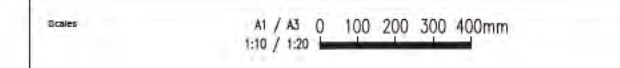
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**ELEVATION C**  
 TENSION ANCHORS OMITTED FROM VIEW FOR CLARITY  
 SCALE 1:10

**REINFORCEMENT OPTION 3** (REFER NOTE 'ALTERNATIVE REINFORCEMENT OPTIONS')  
**POST FOUNDATION PLAN - REINFORCEMENT CAGE MADE FROM N16 BARS**  
 SCALE 1:10

**REINFORCEMENT OPTION 1** (REFER NOTE 'ALTERNATIVE REINFORCEMENT OPTIONS')  
**POST FOUNDATION PLAN - USING TWO SQUARE CAGES THAT HAVE N12 AND N24 BARS AS SHOWN ON DRG CI-GD-06 AND CI-GD-07**  
 SCALE 1:10  
 Reinforcement used for Footings BCB8, 16, 24, 32, 40 & 48. Not used. Project descope and hence not applicable.

**\* ALTERNATIVE REINFORCEMENT OPTIONS:**  
 OPTION 1: USE TWO ALREADY PREFABRICATED SQUARE CAGES AS PER DRG CI-GD-06 AND CI-GD-07 (MADE FROM N24 LIGATURES AND N12 BARS), AND ADD BARS AS SHOWN ON THIS SHEET FOR OPTION 1  
 OPTION 2: USE ONE PREFABRICATED SQUARE CAGE AS PER DRG CI-GD-06 AND CI-GD-07 AND MODIFY BY SPACING THE N24 LIGATURES AT 200 CRS OVER THE 1.9M LONG FOOTING, AND INSTALL N16 BARS IN ALL OTHER DIRECTIONS INSTEAD OF THE N12 BARS AS SHOWN IN DETAILS FOR OPTION 1. (DETAILS FOR OPTION 2 NOT SHOWN ON DRAWINGS)  
 OPTION 3: USE REINFORCEMENT CAGE CONSISTING OF N16 LIGATURES AND BARS, AS SHOWN IN DETAILS ON THIS SHEET FOR OPTION 3

- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - REFER TO DRAWINGS CI-GD-01 AND CI-GD-02 FOR ANCHOR DETAILS.
  - REFER TO DRAWING CL-CI-01 FOR PROPOSED BARRIER FOUNDATION SETOUTS.
  - DRAWING TO BE READ IN CONJUNCTION WITH DRAWING CI-GD-11, CI-GD-12 AND CI-GD-13.
  - ES DENOTES EVENLY SPACED.
  - REINFORCEMENT DETAILS FOR POST FOOTINGS FOR MARINE 2 BARRIER AT CH. 114.16 AND CH. 114 ARE AS PER DETAILS SHOWN ON THIS DRAWING BUT WITH ANCHOR ARRANGEMENT AS PER CI-GD-13.
  - FOR GROUND ANCHOR SCHEDULES REFER TO DRAWING CI-GD-03.



Issue	Date	By	Chkd	Appd

Issue	Date	By	Chkd	Appd
C	28/10/21	MA	JG	EF
REVISED AS CLOUDED				
B	19/10/21	MA	JG	EF
REVISED AS CLOUDED				
A	10/09/21	ML	JG	EF
ISSUED FOR CONSTRUCTION				

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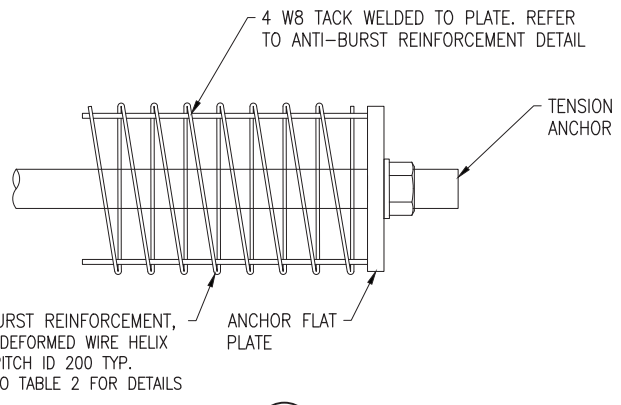
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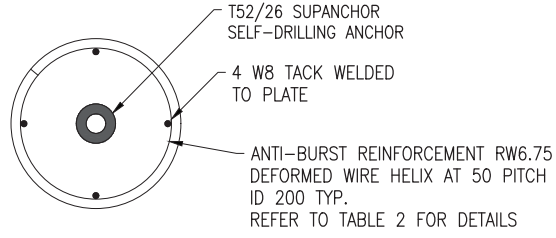
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Drawing Title  
**LANDSLIDE MITIGATION POST FOOTING REINFORCEMENT DETAILS - SHEET 10**  
 Drawing Status  
**ISSUED FOR CONSTRUCTION**  
 Job No  
**268575-00**  
 Drawing No  
**CI-GD-10**  
 Issue  
**C**



VIEW  
SCALE 1:5



**POST FOUNDATION ANTI-BURST REINFORCEMENT DETAILS**  
SCALE 1:5

**TABLE 2: ANTI-BURST REINFORCEMENT – HELIX DETAILS**

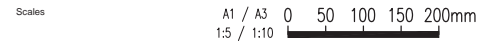
LOCATION	HELIX	PITCH (mm)	INNER DIAMETER ID (mm)	No. OF TURNS
BOAT CLUB BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	10
MARINE 2 BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	8
MARINE 1 BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	10
CHRISTMAS ISLAND CLUB BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	8
COMPRESSION STRUT POST MARINE 2 BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	8
END POST MARINE 2 BARRIER	RW6.75 DEFORMED WIRE HELIX	50	200	10

Project descope and hence not applicable.

**NOTES**

- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
- REFER TO DRAWINGS CI-GD-01 AND CI-GD-02 FOR ANCHOR DETAILS.
- REFER TO DRAWING CL-CI-01 FOR PROPOSED BARRIER FOUNDATION SETOUTS.
- THIS DRAWING TO BE READ IN CONJUNCTION WITH DRAWING CI-GD-10, CI-GD-12 AND CI-GD-13.

**ISSUED FOR CONSTRUCTION**



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A	10/09/21	ML	JG	EF
ISSUED FOR CONSTRUCTION				
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Drawing Title  
**LANDSLIDE MITIGATION POST FOOTING REINFORCEMENT DETAILS - SHEET 11**

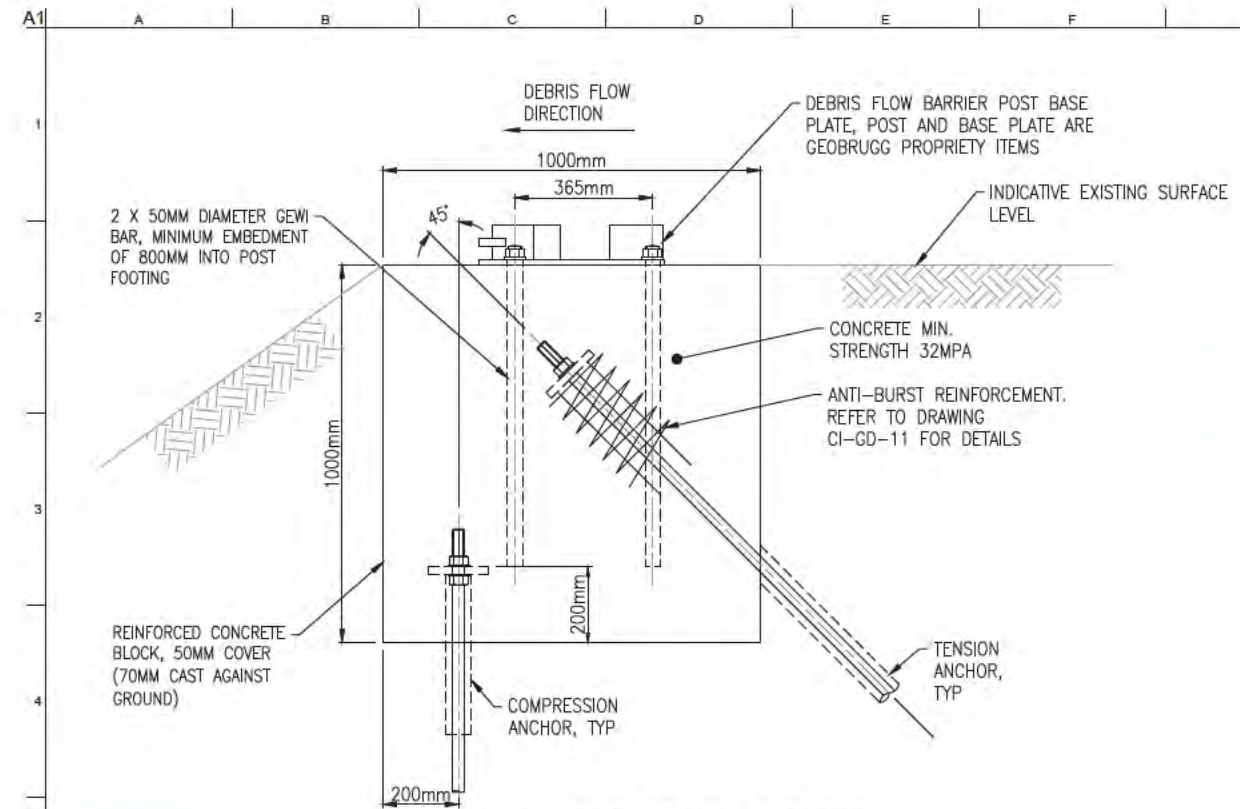
Drawing Status  
**ISSUED FOR CONSTRUCTION**

Job No  
**268575-00**

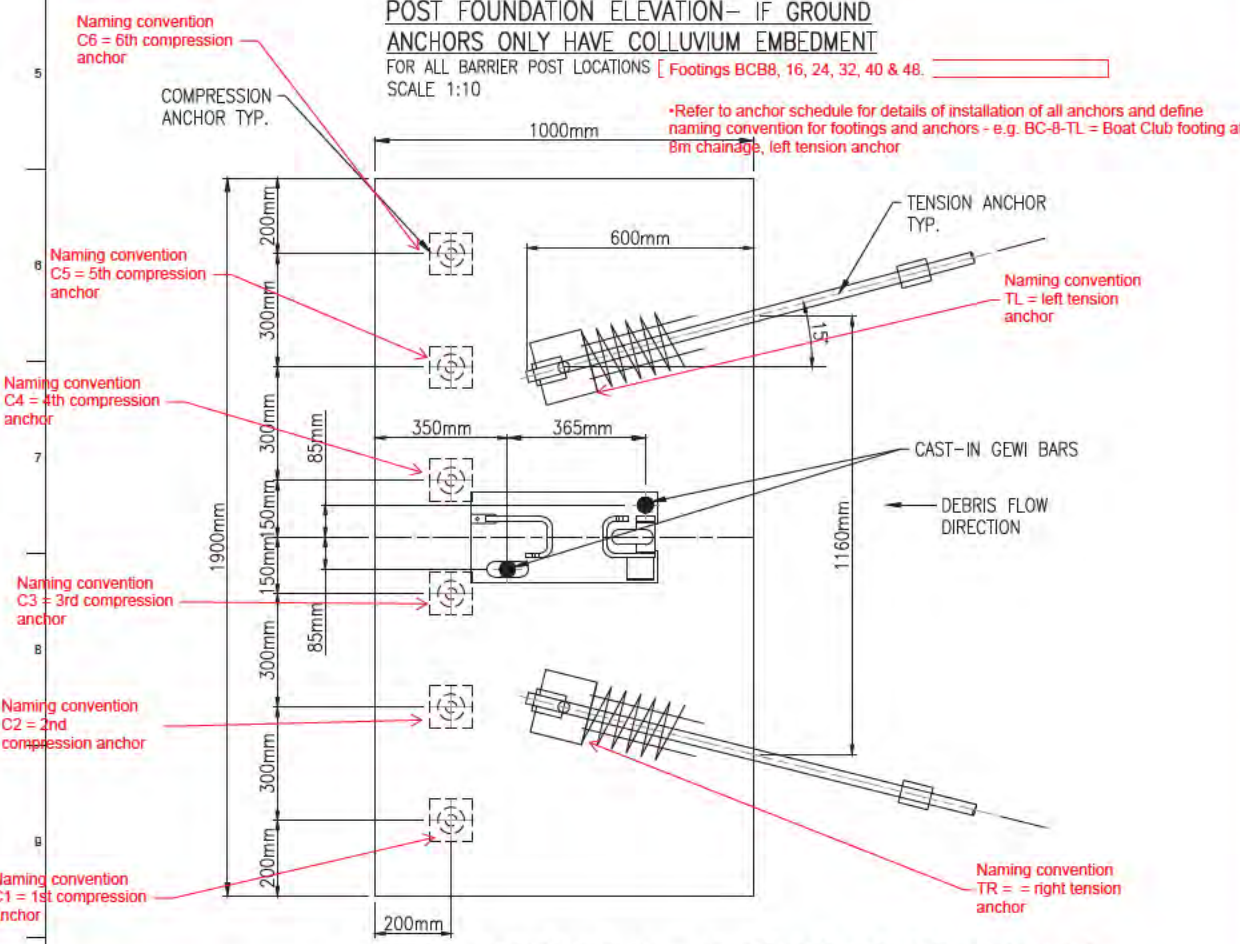
Drawing No  
**CI-GD-11**

Issue  
**B**

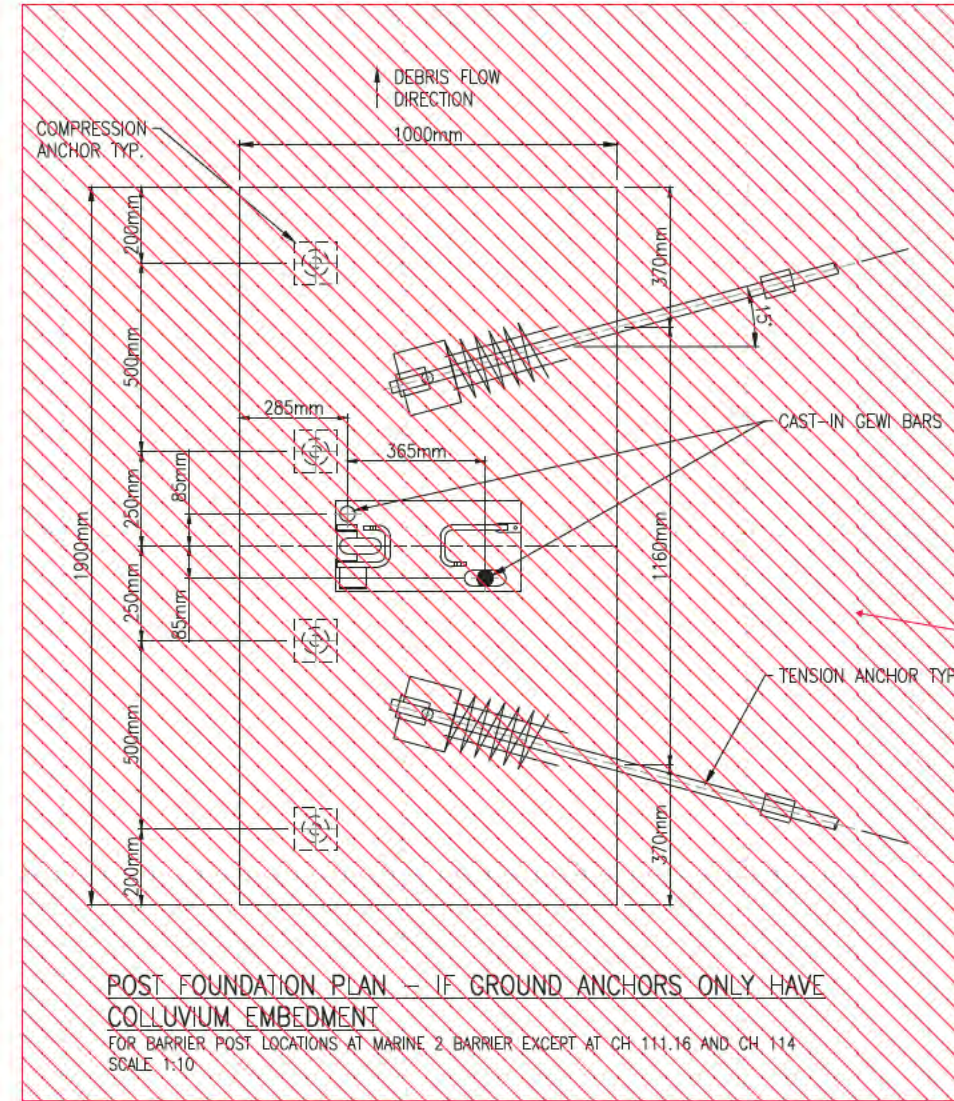
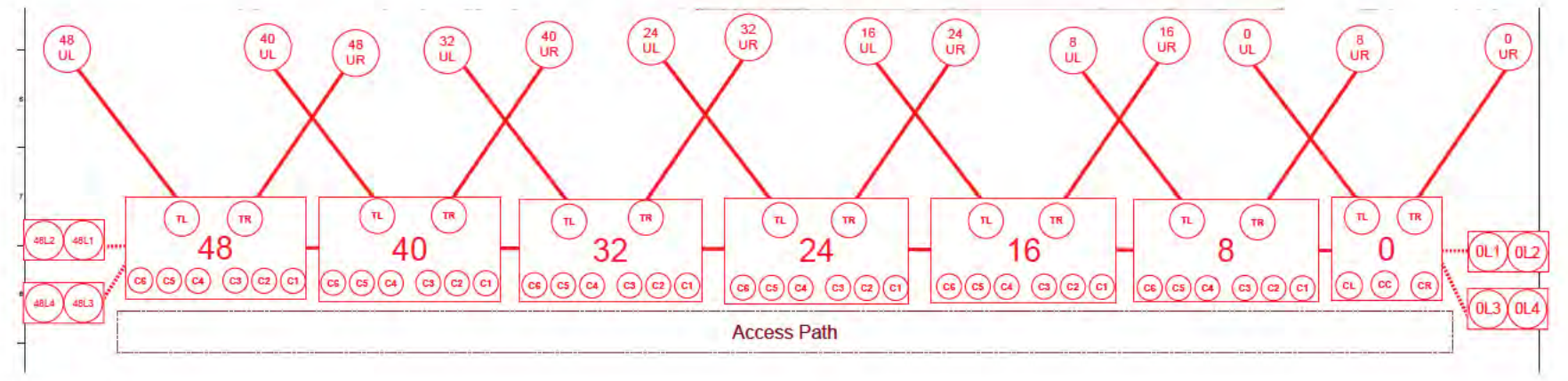
**[DRAWING COLOUR CODED - PRINT ALL COPIES IN COLOUR]**



**POST FOUNDATION ELEVATION - IF GROUND ANCHORS ONLY HAVE COLLUVIUM EMBEDMENT**  
 FOR ALL BARRIER POST LOCATIONS [ Footings BCB8, 16, 24, 32, 40 & 48. ]  
 SCALE 1:10



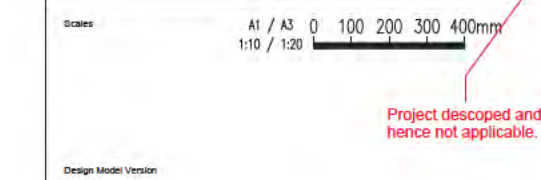
**POST FOUNDATION PLAN - IF GROUND ANCHORS ONLY HAVE COLLUVIUM EMBEDMENT**  
 FOR ALL BARRIER POST LOCATIONS AT BOAT CLUB, FOOTINGS BCB8, 16, 24, 32, 40 & 48.  
 MARINE 1 AND CHRISTMAS ISLAND CLUB  
 SCALE 1:10



**POST FOUNDATION PLAN - IF GROUND ANCHORS ONLY HAVE COLLUVIUM EMBEDMENT**  
 FOR BARRIER POST LOCATIONS AT MARINE 2 BARRIER EXCEPT AT CH 111.16 AND CH 114  
 SCALE 1:10

- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - REFER TO DRAWINGS CI-GD-01 AND CI-GD-02 FOR ANCHOR DETAILS.
  - REFER TO DRAWING CI-CI-01 FOR PROPOSED BARRIER FOUNDATION SETOUTS.
  - FOR REINFORCEMENT DETAILS REFER TO DRAWING CI-GD-10 AND CI-GD-11.
  - FOR GROUND ANCHOR SCHEDULES REFER TO DRAWING CI-GD-03.
  - WHERE ALL GROUND ANCHORS WITHIN A FOUNDATION PLAN ARE INSTALLED WITH ROCK EMBEDMENT AS PER DRAWING CI-GD-03 (OR CI-GD-08 FOR MARINE 2 BARRIER END POST AND COMPRESSION STRUT AT CH 111.16 AND CH 114), DETAILS ON DRAWING CI-GD-06 AND CI-GD-07 APPLY FOR THE FOUNDATION.
  - WHERE GROUND ANCHORS ARE INSTALLED WITH ONLY COLLUVIUM EMBEDMENT AS PER DRAWING CI-GD-03 (OR CI-GD-08 FOR MARINE 2 BARRIER END POST AND COMPRESSION STRUT AT CH 111.16 AND CH 114), REFER TO THE FOUNDATION DETAILS SHOWN ON CI-GD-12 AND CI-GD-13.

**ISSUED FOR CONSTRUCTION**



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A	18/10/21	MA	JG	EF
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Job Title  
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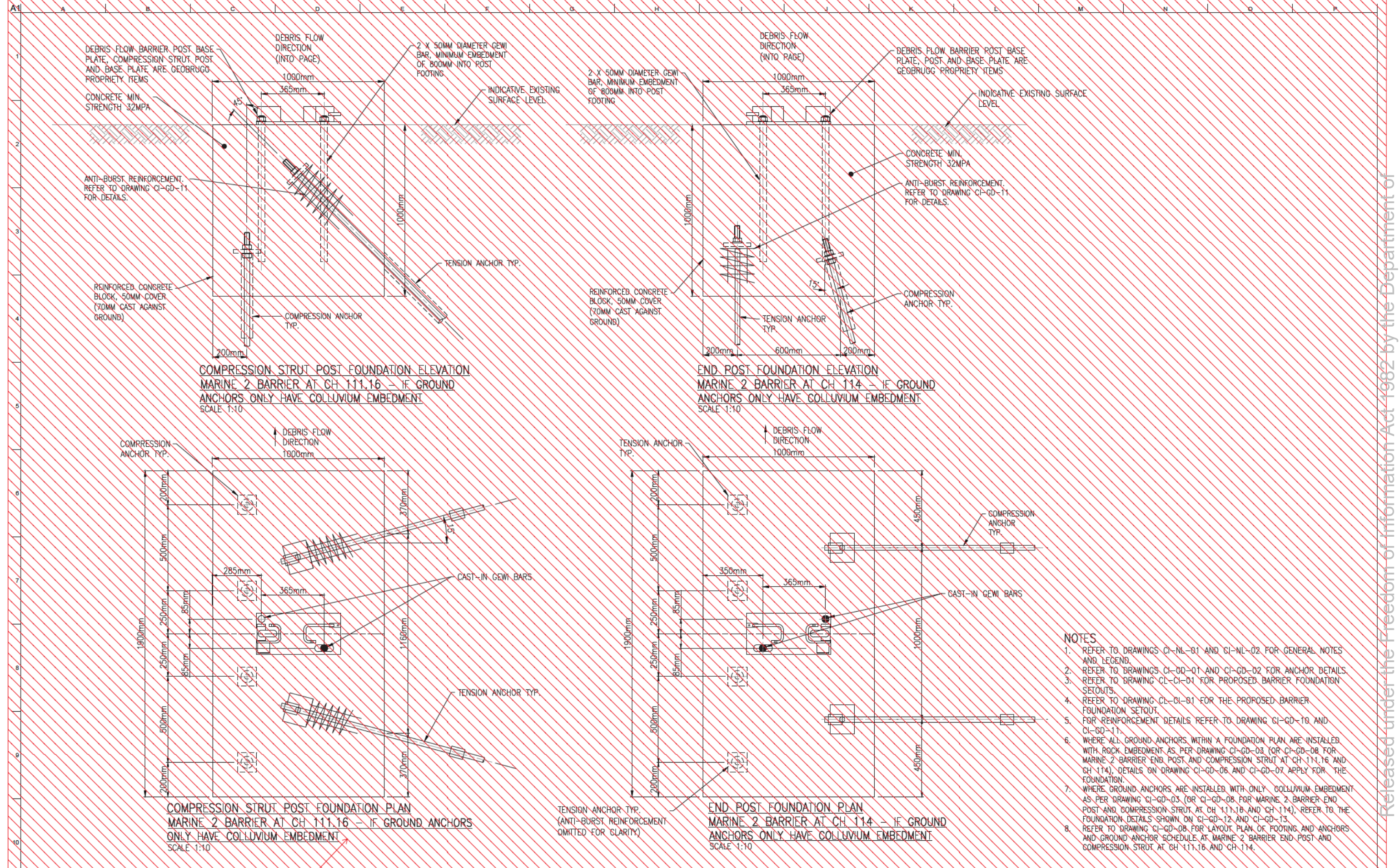
Drawing Title  
**LANDSLIDE MITIGATION POST FOOTING CONCRETE DETS SHEET 12**

Drawing Status  
**ISSUED FOR CONSTRUCTION**

Job No  
**268575-00**

Drawing No  
**CI-GD-12**

Issue  
**A**



- NOTES**
- REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.
  - REFER TO DRAWINGS CI-GD-01 AND CI-GD-02 FOR ANCHOR DETAILS.
  - REFER TO DRAWING CL-CI-01 FOR PROPOSED BARRIER FOUNDATION SETOUTS.
  - REFER TO DRAWING CL-CI-01 FOR THE PROPOSED BARRIER FOUNDATION SETOUT.
  - FOR REINFORCEMENT DETAILS REFER TO DRAWING CI-GD-10 AND CI-GD-11.
  - WHERE ALL GROUND ANCHORS WITHIN A FOUNDATION PLAN ARE INSTALLED WITH ROCK EMBEDMENT AS PER DRAWING CI-GD-03 (OR CI-GD-08 FOR MARINE 2 BARRIER END POST AND COMPRESSION STRUT AT CH 111.16 AND CH 114), DETAILS ON DRAWING CI-GD-06 AND CI-GD-07 APPLY FOR THE FOUNDATION.
  - WHERE GROUND ANCHORS ARE INSTALLED WITH ONLY COLLUVIUM EMBEDMENT AS PER DRAWING CI-GD-03 (OR CI-GD-08 FOR MARINE 2 BARRIER END POST AND COMPRESSION STRUT AT CH 111.16 AND CH 114), REFER TO THE FOUNDATION DETAILS SHOWN ON CI-GD-12 AND CI-GD-13.
  - REFER TO DRAWING CI-GD-08 FOR LAYOUT PLAN OF FOOTING AND ANCHORS AND GROUND ANCHOR SCHEDULE AT MARINE 2 BARRIER END POST AND COMPRESSION STRUT AT CH 111.16 AND CH 114.

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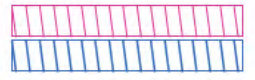
1  
2  
3  
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10

LEGEND:

Fences to be constructed 2020

Treatments

- Treatment A
- Treatment B



Project developed and hence not applicable.

Project developed and hence not applicable.

NOTES

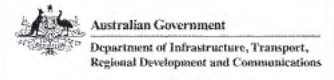
1. REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.

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Scales  
N.T.S

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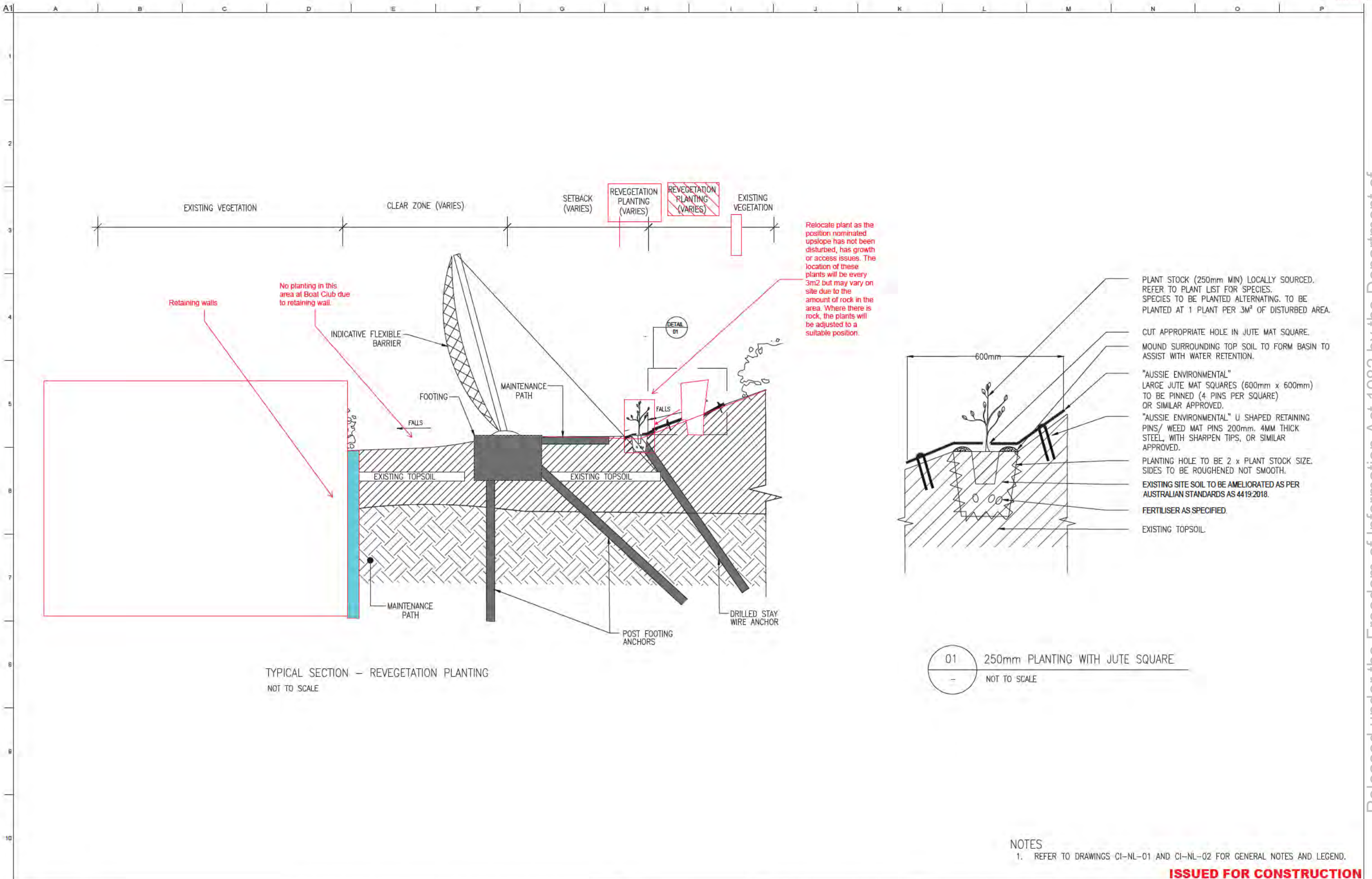


Drawing Title  
LANDSLIDE MITIGATION LANDSCAPE TREATMENT AREAS

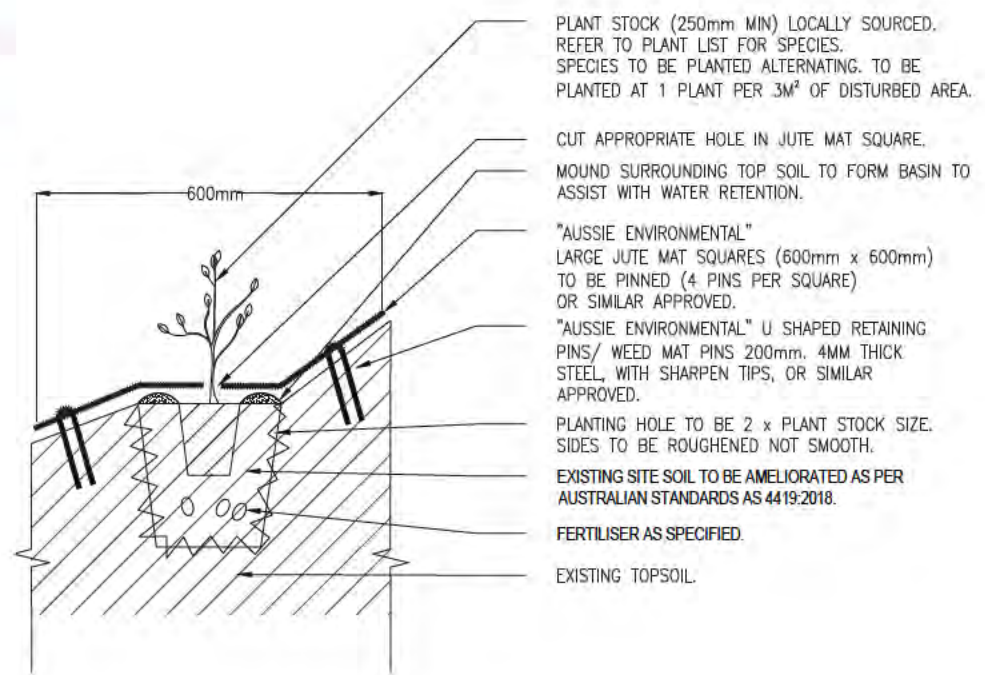
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Relocate plant as the position nominated upslope has not been disturbed, has growth or access issues. The location of these plants will be every 3m<sup>2</sup> but may vary on site due to the amount of rock in the area. Where there is rock, the plants will be adjusted to a suitable position.



01 250mm PLANTING WITH JUTE SQUARE  
- NOT TO SCALE

NOTES  
1. REFER TO DRAWINGS CI-NL-01 AND CI-NL-02 FOR GENERAL NOTES AND LEGEND.

**ISSUED FOR CONSTRUCTION**

Scales: N.T.S.  Design Model Version:	<table border="1"> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> </table>																					<table border="1"> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> </table>																					Australian Government Department of Infrastructure, Transport, Regional Development and Communications	Client: AUSTRALIAN GOVERNMENT DPT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND COMMUNICATIONS	Job Title: FLYING FISH COVE CHRISTMAS ISLAND LANDSLIDE MITIGATION DETAILED DESIGN	ARUP Level 4 108 Wickham Street Fortitude Valley QLD Australia 4006 Tel: +61 (0)7 320 9320 Fax: +61 (0)7 320 9321 www.arup.com	Drawing Title: LANDSLIDE MITIGATION REVEGETATION DETAILS
Issue Date By CHG Appd A 03/08/20 RB JG EF ISSUED FOR CONSTRUCTION	Issue Date By CHG Appd A 03/08/20 RB JG EF ISSUED FOR CONSTRUCTION	Engineering Certification (CEng) Name: _____ Date: _____ Signature: _____	Scale at A1: NTS Discipline:	Drawing Status: <b>ISSUED FOR CONSTRUCTION</b> Job No: 268575-00 Drawing No: CLR-02 Issue: A																																											

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# Department of Infrastructure & Regional Development and Cities

## Flying Fish Cove, Christmas Island Quantitative Landslide Risk Assessment

July 2018

## Executive summary

GHD were engaged by the Department of Infrastructure & Regional Development and Cities (DIRDC) to carry out a Quantitative Landslide Risk Assessment (QRA) for Flying Fish Cove, Christmas Island, Indian Ocean. This report presents the results of field observations, historical research, reviews of previous geotechnical studies and emergency management procedures, geotechnical modelling, and the estimated risks of 'loss of life' to individuals posed by landslides in an area known as the Kampong in Flying Fish Cove. Infrastructure within the Kampong includes apartment style housing, a small shop, religious buildings, marine and port facilities and a boat ramp.

Since the early 1990's a considerable number of geotechnical studies have been commissioned to assess landslide hazards at Flying Fish Cove. Following the studies in the mid-1990's the Parliamentary Joint Committee on Public Works carried out a public hearing into the implementation of rockfall risk reduction strategies for Christmas Island on 11 July 1996. One of the key outcome of the committee hearings was that the Commonwealth has a responsibility to implement measures designed to reduce the risk of fatality at various locations in Flying Fish Cove. A number of buildings considered to be at greatest risk were subsequently demolished and defensive measures comprising rockfall barriers and earth berms were constructed across the foot of the escarpment to provide further protection.

The Parliamentary Joint Committee on Public Works recommended the development of a Rockfall Risk Management Plan (RRMP) for Flying Fish Cove. The RRMP included the establishment of a rockfall research program aimed at increasing the understanding of rockfall hazards and cataloguing rockfall events. Following the construction of the defensive methods and the implementation of the RRMP, no further assessments of landslide or rockfall risk have been carried out at the site.

The early studies, performed prior to the Parliamentary hearings, concluded that the dominant slope process that could impact the community in the Kampong was rockfalls from cliffs located on the escarpment above the cove. However, in 2014, 2016 and 2017 a number of large debris flow landslides occurred at various locations across the site, with one landslide in 2017 engulfing a parked car. The recent debris flows damaged or demolished the rockfall barriers which were not designed to mitigate against such hazards. Our research indicates that potentially larger debris flows occurred in 1935, destroying a number of houses. These hazards were not assessed in detail in the majority of the previous studies and are not considered in the current RRMP.

The modelling, assessments and landslide history research carried out as part of this study indicate that debris flows and rockfalls have the potential to reach a number of buildings and areas commonly used by individuals living, visiting or working in the Kampong.

Using data from available sources, GHD has developed a landslide volume frequency model to predict the long term average number and volume of landslides reaching the toe of the escarpment per year. This model has been used as a basis for undertaking a Quantitative Landslide Risk Assessment (QRA) for the site. The purpose of the QRA is to estimate annual risks of 'loss of life' to individuals at locations affected by landslides in the Kampong. The main findings of the QRA are as follows:

- The estimated annual risks of 'loss of life' to individuals most at risk exceed the Australian Geomechanics Society's (AGS 2007c) suggested tolerable risk criteria. We are not aware whether DIRDC has established tolerable risk levels for the Kampong. In our experience, the estimated risks would exceed the tolerable risk levels of many government departments and agencies.

- The areas at highest risk of 'loss of life' include the Boat Club area, Marine Building, Madrasa and the adjacent shop.
- The highest risks at the site are those associated with debris flows, however rockfalls still pose a considerable risk to life.
- The areas in the Kampong associated with high levels at risk are all located in areas without defensive berms. The reason berms were not constructed in these areas is not known.

A decision on the tolerable or acceptable level of risk for the Kampong is required by DIRDC. This is needed to guide future decisions for the Kampong such as suitable risk mitigation works. This report provides a number of recommendations aimed at reducing risks at the site to acceptable levels and improving the risk management procedures on Christmas Island. These include:

- Upgrading the landslide defences at the site through construction of a series of reinforced soil embankments (i.e. berms) to provide long term protection from both debris flow and rockfall hazards. Such embankments could be constructed from locally sourced soils and or rock material and will require little ongoing maintenance.
- As the RRMP does not consider debris flow hazards that pose the highest risks to life at the site, the RRMP is to be thoroughly reviewed and updated in light of the findings of this study.
- A UAV (Drone) LiDAR survey should be carried out to obtain higher resolution survey data for the whole of Flying Fish Cove.
- Suggested improvements to the Rockfall Research Program.
- Testing and investigation of the existing landslide defences (rockfall barriers and berms) to help assess the current capacity of these structures to provide protection from rockfalls and debris flow.

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- Appendix C – Results of Rockfall Modelling
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# 1. Introduction

## 1.1 Purpose of this Report

GHD has been engaged by the Department of Infrastructure & Regional Development and Cities (DIRDC) to carry out a Quantitative Landslide Risk Assessment (QRA) for Flying Fish Cove, Christmas Island. This study is an extension of the annual slope stability inspections being carried out by GHD under Service Agreement PR10014769 for "The Provision of Geotechnical Inspections and Advisory Services on Christmas Island".

This report presents the results of a Quantitative Landslide Risk Assessment carried out for Flying Fish Cove, Christmas Island. The purpose of the report is to advise DIRDC on the risks landslides pose to both people and property in Flying Fish Cove and recommend options to mitigate and manage these risks.

## 1.2 Scope and Limitations

The scope of work for this project is summarised below:

- Site visit by a Principal Engineering Geologist (Andrew Hunter) and Principal Geological Engineer (Alison Jennings) from GHD.
- Hazard assessment.
- Frequency / likelihood analysis.
- Consequence analysis.
- Risk estimation and evaluation.
- Evaluation of options for landslide risk management.
- Prepare a report summarising the Landslide Risk Assessment (This report).

*This report: has been prepared by GHD for Department of Infrastructure & Regional Development and Cities (DIRDC) and may only be used and relied on by DIRDC for the purpose agreed between GHD and DIRDC as set out in section 1.1 of this report.*

*GHD otherwise disclaims responsibility to any person other than DIRDC arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.*

*The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.*

*The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.*

*GHD has prepared this report on the basis of information provided by DIRDC and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.*

## 2. Definitions and Terminology

### 2.1 Landslide Risk Terminology

The terms used to describe landslide risk throughout this report are as defined by AGS (2007c). The main terms used through this report are as follows:

- **Acceptable Risk** – A risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable
- **Consequence** – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.
- **Elements at Risk**. The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by the landslide hazard.
- **Frequency** – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability.
- **Hazard**. A condition with the potential for causing an undesirable consequence (the landslide). The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material and the probability of their occurrence within a given period of time. Landslide hazard includes landslides which have their source in the area or may have their source outside the area but may travel on to or regress into the area.
- **Individual Risk to Life** – The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.
- **Landslide**. The movement of a mass of rock, debris, or earth (soil) down a slope. The AGS landslide risk management publications use the term 'Landslide' to broadly describe all forms of mass movement.
- **Likelihood** – Used as a qualitative description of probability or frequency.
- **Quantitative Risk Analysis** – An analysis based on numerical values of the probability, vulnerability and consequences and resulting in a numerical value of the risk.
- **The Regulator** will be the responsible body/authority for setting Acceptable/Tolerable Risk Criteria to be adopted for the community/region/activity, which will be the basis for setting levels for Acceptable and Tolerable Risk in the application of the risk assessment guidelines.
- **Risk**. A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability and consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.
- Risk is further defined as:
  - a. For life loss, the annual probability that the person most at risk will lose his or her life taking account of the landslide hazard and the temporal spatial probability and vulnerability of the person.
  - b. For property loss, the annual probability of the consequence or the annualised loss taking account of the elements at risk, their temporal spatial probability and vulnerability.

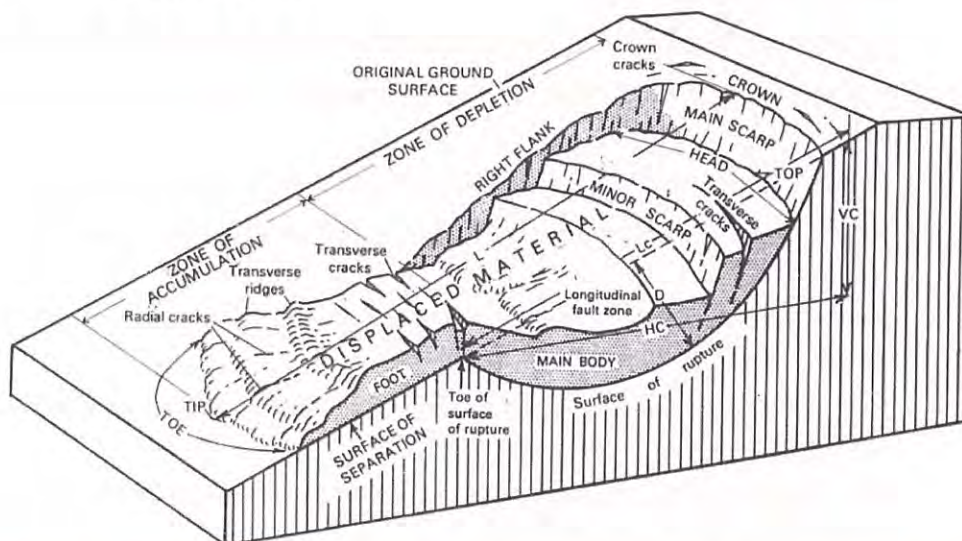
- **Societal Risk** – The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental and other losses.
- **Tolerable Risk** – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.
- **Vulnerability** – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

## 2.2 Landslide Nomenclature

The classification of landslides in this report follows the scheme of Cruden and Varnes (1996). The following landslides are commonly referred to in this report:

- **Debris Flow** - Very rapid form of mass movement in which loose soils, rocks and organic matter combine with entrained air and water to form a slurry that then flows downslope. The flow is a broken up mass of material that no longer retains its original structure or fabric.
- **Rockfall** – Abrupt movement of rocks that become detached from steep slopes or cliffs. Mass in motion travels most of the distance through the air and includes free fall, bouncing and rolling.
- **Slide** - A downslope movement of soil or rock mass occurring dominantly on surfaces of rupture or on relatively thin zones of intense shear strain.

Terms used to describe features associated with landslides are based on Varnes (1978) as illustrated in Figure 1 below.



**Figure 1. Block diagram of idealised landslide showing common features and associated terms (Varnes 1978)**

## 3. Background Information

### 3.1 Previous Studies and Information

Since the early 1990's a considerable number of geotechnical studies have been commissioned to assess landslide hazards at Flying Fish Cove. However, the 1995 study by Golder Associates is the only landslide risk assessment carried out at the site. While there has been a number of assessments and inspections since this time, none of these have assessed landslide risk. It is also important to note that the 1995 study was carried out prior to the publication of the Australian Geomechanics Society (AGS) benchmark guidelines on Landslide Risk Management and slope management and maintenance. These guidelines, published in 2007, provide a national landslide risk management framework for Australia.

Risk assessments do not appear to have been updated following the implementation of the rockfall risk mitigation works that were implemented in the years following 1995, so the current risk posed by landslides is not known.

Despite the studies carried out at the site there are a number of inconsistencies and uncertainties that primarily relate to the landslide mitigation measures that have been implemented at the site. These issues probably arose due to the turnover of department staff on the island as well as the number of different consultants that have been involved during this time. Some of these uncertainties will be discussed throughout this report.

The following inventory of reports, studies and documents relating to landslide activity and mitigation works at Flying Fish Cove have been reviewed as part of this study. This information, in particular information relating to landslide volume and frequency, has been relied upon for this study. The following documents were either provided by DIRDC or sourced by GHD.

- 1972 Report on rockfall and land-slip at north end of Flying Fish Cove on 21 March 1972; British Phosphate Commissioners.
- 1988 Letter from C.R. L White for the Christmas Island Administrator (Not available).
- 1992 Report on an initial assessment of the stability of some of the cliff faces above Flying Fish Cove. Golder Associates.
- 1995 (March) Letter report on inspection of large rockfall. Golder Associates.
- 1995 (October) Landslide risk assessment Flying Fish Cove Christmas Island. Golder Associates.
- 1997? GHD Archives – Assembly Instructions and Maintenance Instructions for the TSB 11/R rockfall barrier, manufactured by Turbosider®.
- 1997 Implementation of rockfall risk reduction strategies. Commonwealth of Australia. Hansard report on Public Works, Christmas Island.
- 1997 Rockfall risk management plan, Flying Fish Cove, Christmas Island. Department of Environment, Sports and Territories.
- 1999 Inspection of rockfall event of 1 April 1999. Baynes Geologic.
- 2000 Re-assessment of landslide risks Flying Fish Cove, Christmas Island. Baynes Geologic.
- 2003 Annual report on Rockfall risk management plan. GHD.
- 2004 Annual inspection report. GHD.
- 2005 Annual slope stability inspection. SKM.
- 2006 Report on the 2006 annual inspection and five yearly review of the research program. Arup.

- 2008 Annual rockfall inspection. Arup.
- 2009 Annual rockfall inspection. Arup.
- 2010 Annual rockfall inspection. Arup.
- 2010 Seismic Hazard Assessment. Arup.
- 2011 Annual rockfall inspection. Arup.
- 2011 Rockfall risk management plan – 5 Year Review. Arup.
- 2012 Annual rockfall inspection. Arup.
- 2012 Rockfall Barrier Condition Survey. Arup.
- 2013 Annual rockfall inspection. Bowden Geological.
- 2014 Annual rockfall inspection. Bowden Geological.
- 2014 Post-cyclone inspection –Flying Fish Cove. Bowden Geological.
- 2015 Annual rockfall inspection Bowden Geological.
- 2016 Post landslide inspection – Flying Fish Cove October 2016. Bowden Geological.
- 2017 Post Landslide inspection – Flying Fish Cove June 2017. Bowden Geological.
- 2017 Rockfall Fence, Kampong, Christmas Island. Assessment of landslide damage and recommendations for remedial works. Arup.
- 2017 Flying Fish Cove – Five-Year Review of Rockfall Research Program. Bowden Geological.
- 2018 Personal communications with representatives from Geobrugg Australia Pty Ltd relating to the supply of various replacement parts for the existing rockfall fence. These communications also included discussions on the original rockfall fence tender (tendered in 1996) and design requirements for the Flying Fish Cove rockfall fence.
- 2018 Personal communications with representatives from Geobrugg Australia Pty Ltd. Geobrugg provided an original drawing of the Turbosider® rockfall barrier configuration as constructed on the site as well as an inventory of parts. These were provided to Geobrugg by Ms Jessica Sullivan (DPIRDC).
- 2018 Annual rockfall inspection. GHD.
- 2018 Rockfall Risk Management Plan, Christmas Island Emergency Management Committee. DIRDC.

### 3.2 Survey

DIRDC provided the results of a LiDAR (Light Detection and Ranging) survey as a digital elevation model (DEM) in the form of a raster file. The date of the survey is not known. The raster image has a cell size of 1m, meaning that features smaller than about 1m in dimension can be lost or averaged down in size. As a result it is apparent that some site features are not accurately represented in the survey. For example, a number of near vertical cliffs observed on site appear as steep slopes in the survey. It should also be pointed out that all structures in the Kampong area have been stripped out (removed) of the LiDAR data provided, leaving only the 'bare earth' topography. The locations of existing rockfall barriers and berms are not surveyed, and their locations on figures attached to this report have been approximated using the aerial imagery supplied by DIRDC.

### 3.3 Parliamentary Joint Committee on Public Works

Following the submission of the 1995 landslide risk assessment report prepared by Golder Associates, the Parliamentary Joint Committee on Public Works carried out public hearings into the implementation of rockfall risk reduction strategies for Christmas Island on 11 July 1996. The 2017 Bowden Geological report summarised the conclusions and recommendations of the Committee which are reproduced below:

- The Commonwealth has a responsibility to implement measures designed to reduce the risk of fatality at various locations in Flying Fish Cove.
- Before December 1996, the Department of Environment, Sport and Territories should have ready a rockfall risk management plan for Flying Fish Cove which identifies events, documents responses, assigns responsibilities, requires continuous research and monitoring, and increases community awareness of risk and dangers. Simulated exercises should be undertaken.
- Ficus microcarpa trees should be planted upslope from the rockfall barrier to provide extra protection in the longer term.
- As is evident from the major rockfall in 1972, the Committee believes that the Boat Club site remains a high-risk area. Therefore, the Committee recommends that premises owned by Christmas Island Boat Club should be demolished and a new safer site, proximate to water frontage, and consistent with the Town Plan, be found.
- The Department of Environment, Sport and Territories and Christmas Island Shire Council should give favourable consideration to construction costs of a new club building being wholly or partially funded from the Community Benefit Fund.
- Land for private development is the most pressing need on Christmas Island.
- Block 408 in the Kampong should be demolished at the end of its economic life, expected to be in three to five years' time. (Note that Block 408 was demolished).
- Following the construction of the rockfall barrier and the implementation of a general rockfall risk reduction management plan, the future of Block 412 should be re-evaluated at the end of the same period. However the Committee favours the eventual removal of Block 412. (Note that Block 412 was demolished).
- Dwelling units at the south-west corners of both block, considered to be at greatest risk, should be progressively and permanently vacated.
- The Department of Environment, Sport and Territories, in conjunction with Christmas Island Shire Council, should identify parcels of land for residential and other development that comply with the Draft Town Plan.
- Land for private housing development should be offered without delay.
- The future use of the site of Block 408, post demolition, should not preclude its use as a revegetated area to provide nesting sites for the Christmas Island frigate bird. If Block 412 is demolished, the same uses could apply.
- Potential trade-offs between the use of the sites as recommended and the use of land containing vestiges of primary rainforest, at present not favoured for development by the Australian Nature Conservation Agency, should be investigated.

## 4. Rockfall Risk Management

### 4.1 Rockfall Risk Management Plan

The Parliamentary Joint Committee on Public Works instigated a Rockfall Risk Management Plan (RRMP) for Flying Fish Cove on Christmas Island in 1997 and this document has been revised a number of times since. The current RRMP was issued by DIRDC in March 2018.

The purpose of the RRMP is to reduce the risk of injury or death to individuals and the risk of damage to property, from rockfall in Flying Fish Cove and road to Smith Point area of Christmas Island. The objectives of the Rockfall Risk Management Plan - Flying Fish Cove and Road to Smith Point are:

- To detail those strategies and actions that should be implemented to reduce the risk of rockfall impacting upon the individuals, community and facilities.
- To increase the community awareness about the rockfall hazard, its causes and mitigation efforts.

The Plan does not address actions required in the event of a significant rockfall. If this were to occur the Territory Controller would assume responsibility, under the Christmas Island Emergency Management Plan.

The RRMP prescribes two levels of rockfall warnings: Level 1 and Level 2. These are defined in the RRMP as:

- Level 1 condition - possible indicators of a potential event.
- Level 2 condition - probable indicators of a likely event.

**Table 1. Summary of RRMP alarm level rainfall conditions**

6	Rainfall in any 1 hour	Rainfall in any 24 hour period
1	52 mm	163 mm
2	113 mm	356 mm

### 4.2 Rockfall Research Program

One element of the RRMP was to undertake a program of research into rockfalls in the Cove. The RRMP describes the objectives of this research as follows:

*"The objective of the research activity is to increase the current understanding of natural methods of stabilising and controlling the movement of cliffs and arresting the motion of those rocks which are dislodged in a rockfall event. The research will also provide a database to better characterise the rockfall hazard and thus improve the assessment of rockfall risk. The research process will also provide a feedback mechanism for the evaluation of the Rockfall Risk Management Plan."*

Since 2003, this has involved annual assessments of the slopes above Flying Fish Cove as well as visual assessments of the rockfall barriers. Every 5 years a five-year review is prepared to provide DIRDC with a summary of the assessments over the preceding period.

Annual rockfall inspection reports have been prepared by various consultants following each of the annual inspections. The focus and content of each report varies from year to year and from consultant to consultant, with many of the reports re-iterating content from previous reports. Content that is common to most of the reports includes:

- Summary and review of monthly rockfall inspections undertaken along the rockfall fences by DIRDC.
- Observations of rockfall fence and berm conditions.
- Updates to the rockfall and landslide inventory for the site.
- Summary of observations from inspections of cliffs and slopes (where accessible). The areas inspected vary from year to year.
- Rockfall records collected by DIRDC are also reviewed and a report prepared on the findings and any changes to the slopes which may affect landslide and rockfall risk.

## 5. Fieldwork

A site visit to Flying Fish Cove was carried out by our Principal Engineering Geologist, Andrew Hunter and Principal Geological Engineer, Alison Jennings between 22 and 26 May 2018. The purpose of the site visit was to:

- Review and verify previous geotechnical inspection reports carried out at the site.
- Observe and characterise the nature of landslide hazards and processes at the site.
- Assess potential elements at risk of landslide activity (i.e. buildings and areas where people may be present).

The site visit included:

- Walkovers along the crest of the escarpment.
- Walkovers along the entire length of the rockfall fences and berms.
- A number of walkovers through the Kampong to observe potential elements at risk of landsliding such as roads, buildings and areas where people may visit or congregate.
- Traverses of selected accessible areas of the escarpment slopes including:
  - The slopes above the 'Boat Club' area and Marine Building. These inspections reached the first near-vertical cliff-line, beyond which the terrain is not accessible on foot.
  - The slopes above rockfall fences '412A' and '408'. This included walkover of the path of the '412' landslide to the vicinity of the main scarp of the landslide. The slopes beyond this area were too steep to safely access on foot.

## 6. Site Description

Christmas Island is located in the Indian Ocean, approximately 2,600 km northwest of Perth, and 490 km south-southwest of the Indonesian capital of Jakarta. Flying Fish Cove is located on the north west side of the island and contains a series of apartment style housing, and associated infrastructure known as the Kampong. The cove also contains the marine facility for the port, a commercial jetty and the most popular boat ramp on the island. The general layout of Flying Fish Cove, with the location of rockfall fences and berms, is shown on Figure A1, presented in Appendix A. The figure presents the major structures, roads and general elements of the site that are mentioned within this report.

Flying Fish Cove comprises a 200 m high arcuate, coastline that faces northwest. The cove is surrounded by a narrow coastal plain which is up to 100 m wide. This coastal plain hosts a number of residential, cultural and commercial elements of the Island community.

## 7. Geology

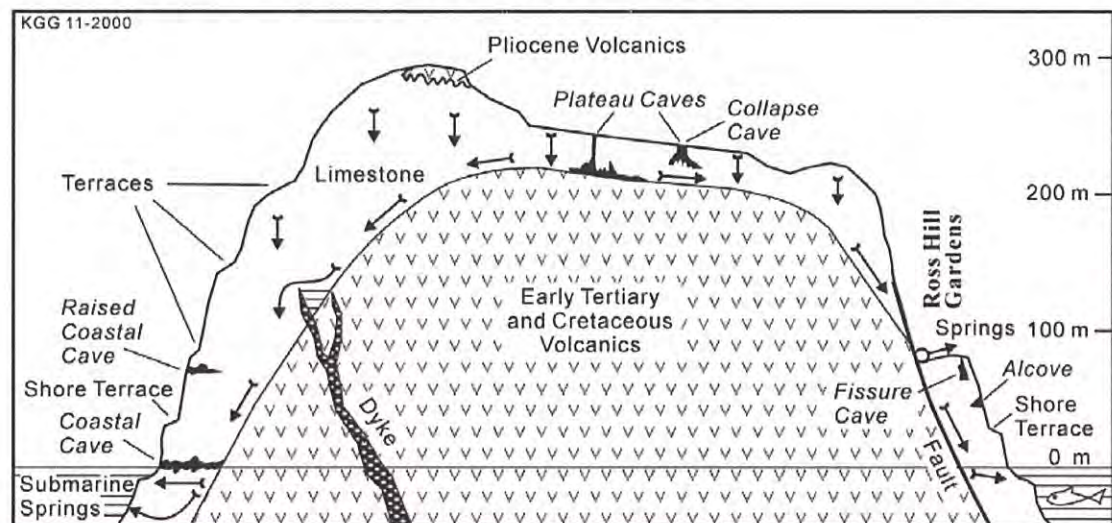
### 7.1 Regional Geology

The geology of Christmas Island has been described in published maps and records, initially through site reconnaissance in the later 19<sup>th</sup> Century (William, 1900) performed as part of the overall identification and assessment of potential phosphate deposits. Subsequently, mapping and reporting of the islands geological conditions has been typically undertaken in association with the mineral extraction industry, with published and unpublished reports held by Christmas Island Phosphates Limited.

A number of geological reports suggest that Christmas Island is an exposed cap of a seamount, sitting above the Wharton Basin of the Indian Ocean. The seamount is one of a number of underwater, extinct volcanoes that formed about in the late Cretaceous Period (from about 80 Ma).

The island core has been described as typically consisting of basic volcanic rocks, including basalts, andesites and trachybasalts. This core is overlain by an interbedded sequence of limestones, volcanic intrusions and minor dolomites. A thick blanket of phosphate deposits top the island plateau.

A diagrammatical representation of the island geology is shown in the following figure, reproduced from Grimes (2001). The cross section, presented with a vertical exaggeration of 10 times, shows the general groundwater flow direction through the limestone



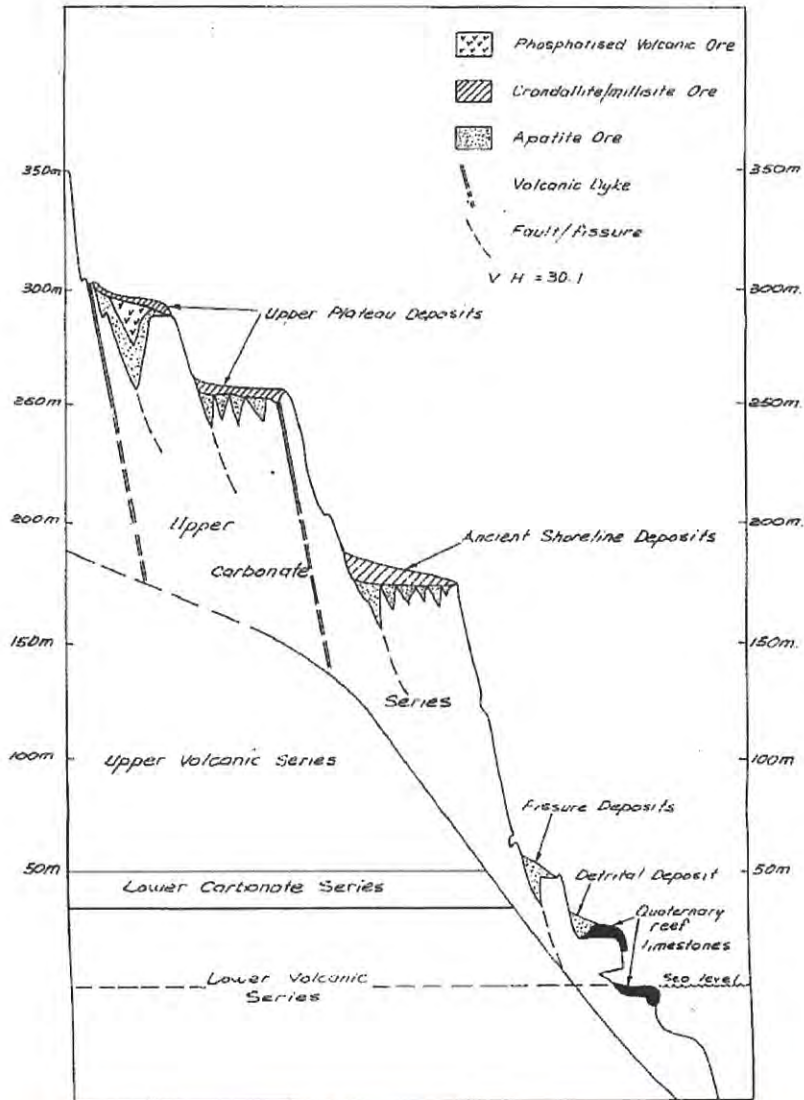
**Figure 2 – Diagrammatical Cross Section of Christmas Island**

### 7.2 Geology of Flying Fish Cove

The geology of Flying Fish Cove was mapped and reported in Golder (1992 and 1995), with Baynes (1999) providing additional mapping of the geomorphological processes within the cove.

The mapping exercises have indicated that the cove potentially represents a down thrown fault block or graben system, constrained by two near vertical boundary faults to the north and south of the cove, running in a north west-south east direction.

The slopes of the cove are described as a sequence of limestone and volcanic dykes, generally dipping into the slope toward the south-east at angles of up to 50°. The limestone has been mapped as heavily jointed and faulted, with major defects frequently dipping steeply out of the slope. A generalised cross section of the cove was provided in Golder (1995) and reproduced in Figure 3.



**Figure 3 – Conceptual Geological Cross Section of Flying Fish Cove**

### 7.3 Geomorphology

The topography of the cove slopes is shown on the terrain map, Figure A2, developed from data supplied to GHD. Cross sections A to E presented in Figures A4 to A9 have been prepared to illustrate the topography across different areas the cove. These are also annotated with key site features and predictions on landslide behaviour and will be referred to throughout this report. The escarpment comprises of steep talus slopes interspersed with stepped cliff-lines and rock exposures. The talus slopes are typically between 30° and 40° and comprise loose rock debris ranging from gravel size to large boulders several metres across (Figure 4).

The overall slope is generally stepped in profile and comprises a number of steep (35° to 40°) slope elements, separated by sub-vertical cliffs, that occur particularly near the upper part of the slope (Figure 4). The western part of the Cove is narrower and particularly steep and comprises predominantly cliffs. The main cliff-line that caps the escarpment is up to about 40m high. This cliff-line is for the most part not accessible due to the steep slopes and smaller intermediate cliffs below. A secondary cliff line is located about one-third of the way down the escarpment and is up to about 20m high. This cliff-line transitions into a series of broken cliffs towards the north and before petering out complexly. Where GHD observed this cliff-line above the Boat Club / Marine Building area, it was found to be extensively covered by Banyan Trees and the associated roots (Figure 5).

The slopes are generally densely vegetated with mature trees and seasonal undergrowth. The density of trees and undergrowth typically decreases toward the western end of the cove and particularly in the drainage lines where slope processes may be acting to retard growth. Following cyclone Gillian in March 2014, many trees were blown down by the strong winds, particularly at the western end of the Cove. The remains of these trees still litter the upper slopes.



**Figure 4. Talus Slopes Above the Marine 1 Building**



**Figure 5. Secondary cliff line above the Marine 1 Building**

The soils of Christmas Island are derived from two sources - limestone (terra rossa soils) or basaltic extrusive rocks (krasnozem soils). The 1995 Golder report also provided a review of the superficial deposits across the cove, indicating:

- Extensive rockfall accumulations consisting of gravel to boulder sized angular to subangular fragments of high strength rock.
- Older, uncemented accumulations of rockfall debris on which soil profiles and vegetation have developed.
- Cemented colluvial deposits, which were assessed as being associated with former, extensive landslides.
- Raised beach deposits, consisting of partially cemented boulder beds and rockfall debris, cemented by coral. These form subdued terraces approximately 30m to 40m above sea level, on which the former Christmas Island Club sits.

The soils on the slopes appear to be typically fairly thin based on the widespread occurrences of rock exposures and soil exposures we observed in landslide scarps. For example, the soil profile exposed in the flank of the 'Basketball Court' landslide is only about 1m to 1.5m thick and overlies an irregular rock profile (Figure 6). The soils appear to contain highly variable mixtures of clay and gravel, with clay contents estimated to be up to about 20%.

The role the Christmas Island Red Crabs (*Gecarcoidea natalis*) play in modifying the geotechnical properties of the upper layer of soil on the slopes is somewhat uncertain as it has never been studied. Green (2004) studied the burrow dynamics of the crabs and reported that mean burrow densities remained relatively stable over a two-year period, fluctuating between 1.4 and 1.6 burrows /m<sup>2</sup>. Green (2004) also reported that the burrows were quite long lived structures with a mean turnover time of 4.4 years. The study also indicated that soil disturbance in coastal areas was likely to be much higher in coastal areas due to the crabs breeding and migration activities. From a geotechnical perspective it stands to reason that the crab activity probably loosens the upper approximately 0.5 m of the soil profile and may also increase the permeability of the colluvial soil.



**Figure 6. Soil Profile (left) Exposed in Flank of Basketball Court' landslide**

## 7.4 Human Influence

Extensive human disturbance of the near surface soils across the cove are known to have taken place, and are reported in a number of the supplied reports. Such historical activities in Flying Fish Cove have generally been involved with the evolution of the mining activities, including:

- Construction of a railway line and cutting at the base of the cove slope, at the northern extent of the cove, following the alignment of the CI Club and 408 rockfall fences, at the approximate RL 20m contour line (Figure 7).
- Construction of a mining 'chute', extending from the top of the slope, through a deep cut in the cliff above the 408 rockfall fence, connecting with the railway cutting. The former phosphate loading area at the base of the gravity chute is a wide, relatively flat area, as labelled in Figure A1 above Berm 1. The area is easily recognisable by the flat topography in Figure A2.
- A conveyor situated at the top of the cliff face, which was constructed on large quantities of construction spoil end dumped over the edge of the cliff, and subsequently has resulted in large volumes of quarried phosphate product to build up at the cliff edge.



**Figure 7. Former Railway Line Area and Cutting (left). 'Christmas Island Club' Rockfall Barrier on Right.**

## 7.5 Hydrogeology and Drainage

Despite its high rainfall, Christmas Island lacks permanent surface water, with nearly all rainfall draining quickly underground to join a karst drainage system. A few perennial streams flow at the Dales, Ross Hill Gardens, The Ravine, Jones Spring, Freshwater Spring, Dolly Beach, Hosnie's Springs and Waterfall.

The island has geologically significant subterranean cave systems, including anchialine cave systems (a subterranean water body with connections to the ocean), which provide habitat for endemic fauna. Water accumulates in the caves and sinkholes at the interface of limestone and the underlying volcanic rock strata. Here it either flows along the interface, as in the case of the flow system from Grant's Well through Jedda Cave and Jane-up Beyond, or flows down fractures in the volcanic rock. The flows along the limestone-volcanic rock interface emerge in some places as springs. There is evidence of a freshwater lens floating on top of underlying seawater and flows just above sea level.

Drainage on the slopes above Flying Fish Cove is poorly developed, however a number of relatively broad and shallow preferred drainage lines exist. Water is generally observed flowing in these drainage lines during periods of particularly intense rainfall. During less intense periods of rainfall, subsurface drainage within the predominantly limestone soils, talus and rock predominate.

A number of known springs occur on the slopes above Flying Fish Cove following heavy rain:

- Spring 1: Immediately above the Christmas Island Club fence at the toe of a cliff.
- Spring 2: Above the Marine 1 fence.

Surface water runoff from the Drumsite area is also thought to flow down the Flying Fish Cove slope from Murray Road.

## 8. Landslide Volume Classification

The magnitudes of landslides discussed in this report have been classified according to the estimated volume of material reaching or passing the existing rockfall barrier. A breakdown of the classification is presented in Table 2

**Table 2 Landslide Volume Classification**


Volume of Debris Reaching or Passing Rockfall Fence (m <sup>3</sup> )	Volume Classification	Typical Dimensions of Landslide	
		Debris (m)	Rockfall Blocks (m)
<0.1	Very Small	-	0.25 x 0.4 x 0.3
0.1 - 1	Small	-	0.6 x 0.6 x 0.6
1 - 10	Medium	4 x 2 x 1 (such as the February 2002 CI Club Fence landslide)	2 x 1.5 x 1 (Such as the April 1999 Boat Club rockfall)
10 -100	Large	9 x 4 x 1.5 (Such as the debris reaching the fences during the Basketball Court landslide)	No single blocks. Multiple blocks, such as March 1972 of 5-6m <sup>3</sup>
100 - 1000	Very Large	Such as the October 2016 Boat Club landslide	Not credible
> 1000	Extremely Large	A number of large and very large landslides, such as April 1935 landslides	Not credible

## 9. Landslide History

A critical element of assessing the risk of landslide occurrences and potential damage/injury is in the understanding of the history of landslides, including the type and volume of such events. An attempt to present a history of landslide records was first put forward in the report by Golder (1992), with a subsequent revision in 1995. Whilst detailed and extensive mapping of hazards and rockfalls within the cove have been performed subsequently, no comprehensive updates to this early work has been undertaken since.

The following section presents a chronological review of the recorded major landslide history within the cove, with information drawn from data supplied by DIRDC and publically available sources. The review focusses on the reported major incidences, however, much of the information prior to the 1992 study is based on anecdotal evidence, such as personal communications and historical documents.

**Table 3. Summary of Major Landslide Events**

Date	Description
1895	<p>Limestone boulders were recorded at the base of the cliff and resting on the reef close to the Boat Club ramp (Andrews, 1900). The timing of the falls is unknown, with trees reported to be growing from individual boulders.</p>
	<p>Photographs of the time present evidence of these boulders, some of which are no longer present, indicate the typical size and travel distance of historical falls.</p>
	
	<p>Photograph of southern section of reef near the Boat Club ramp, note the large boulder in the background (Andrews, 1900)</p>

Date	Description
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Photograph indicating the size of limestone boulders reaching the base of the cliff (unconfirmed location within Flying Fish Cove).



South side of Flying Fish Cove. Note the large boulders sitting on the reef, assessed as large rockfall debris.

Andrews (1900) provides a mention of slight earthquakes one of which on 20 October 1895 that was “sufficiently severe to loosen great masses of rock from the cliff”. The data does not indicate whether the above photographs represent the product of this incident, or earlier, unrelated falls.

1935  
14 April)

Large debris slides and flows resulted in the destruction of a building at the Malay Kampong settlement (close to the current Marine Building location) and across much of the Flying Fish Cove escarpment. The large debris slides damaged or completely destroyed a number of properties at the base of the cliff. Photographic evidence suggests that up to four large debris slides affected the cove, stripping the vegetation across large swathes of the slopes. No rainfall data is currently held relating to the associated weather event, however, a number of sources, including Bowden (2017), suggest that the monthly rainfall close to this date exceeded 1,000mm. Such a rainfall event may represent a greater than 1 in 50 year episode.

The following photographs present a record of some of the damage to the settlement (source, National Archives of Australia)

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Date	Description
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Photograph of three of the 1935 landslides. It is estimated that the far right landslide is potentially coincident with the present day position of the Marine building.



Landslide above the Malay house, from the top of the slide. Note the extent of landslide run out.

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Date	Description
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Photographs of landslide debris behind Howell Jones' house (left) and landslide scarp behind Number 9/10 bungalow (right), unknown current location.

Due to the quality of the historical photographs and their distorted perspective, it is difficult to assess the volume of these large landslides. An estimate, based on projecting the position of the slides on the current aerial images has been performed to estimate both landslide volume and travel distances. The landslides have been conservatively estimated to consist of volumes in the order of 350m<sup>3</sup> to 1,100m<sup>3</sup>.

Figure A3 presents the estimated position of three of the 1935 landslides. We are uncertain as to the accuracy of these positions, however, the photographs suggest these landslides affected the southern half of the cove. Further evidence to suggest the landslides occurred south of previously mapped locations (Bowden, 2016) is the lack of historical records indicating damage to the phosphate infrastructure. The stainless steel phosphate chute was constructed in 1932/33, at a likely significant cost. If the 1935 landslides had affected this infrastructure, it is likely this would have been recorded in the accessible records.

Due to this potential inaccuracy, and without further reliable evidence to suggest the locations, the assessment has used this data with caution. We have used the data to assess the size and run out distance of potential landslide events, but not attributed this to precise areas of the cove.

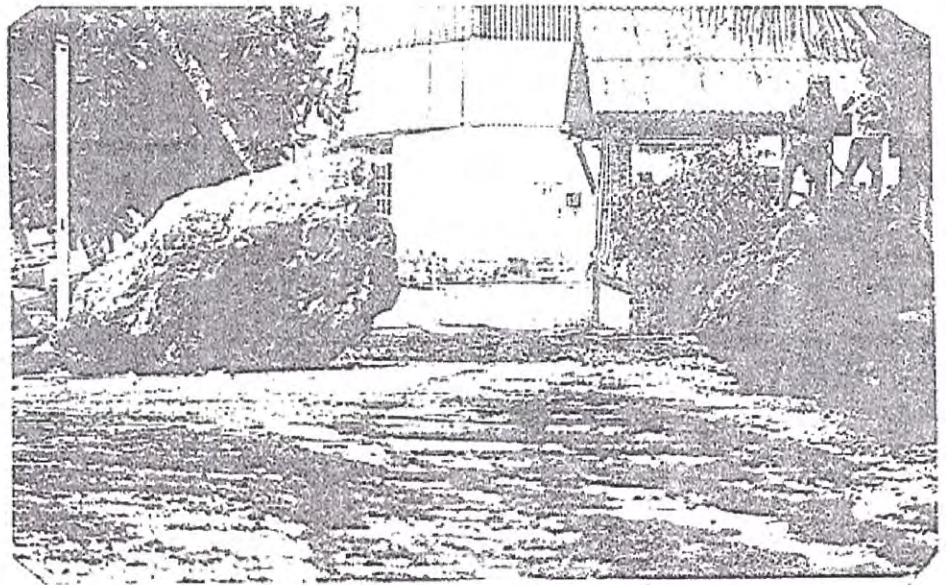
1972  
20-21  
March

A landslide comprising large boulders and debris, potentially originating from the cliffs at approximately RL 120m, directly above the former Boat Club building caused significant damage.

The landslide started with a number of small boulders, up to 0.1m<sup>3</sup>, reached the beach north of the Boat Club, damaging sewer and water pipes. The following day a larger slide, caused the destruction of the Boat Club barbecue area, damaged the Boat Club and damaged a passing motor vehicle. The fall occurred following a sustained rainfall period, where 305mm of rain was recorded over four days.

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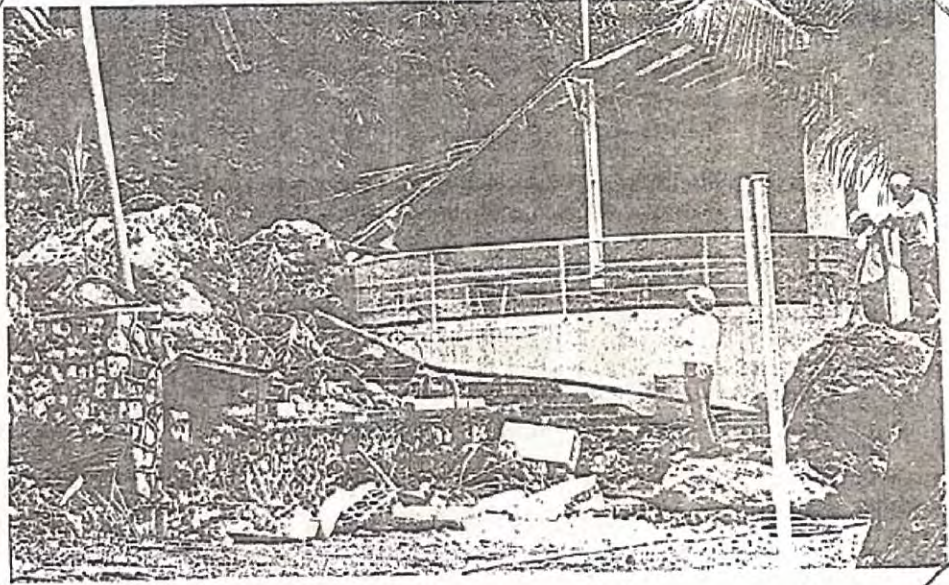
Date	Description
	<p>The damage was primarily caused by four large boulders of palagonite tuff, totalling 12m<sup>3</sup> with the largest boulder 6m<sup>3</sup>. The boulders were observed to come to rest between the barbecue area and the road, with two boulders reaching the beach and sea.</p> <p>The following photographs, reproduced directly from the British Phosphate Commissioner report (Barnett, 1972), present a record of the size and position of the largest of the boulders.</p>



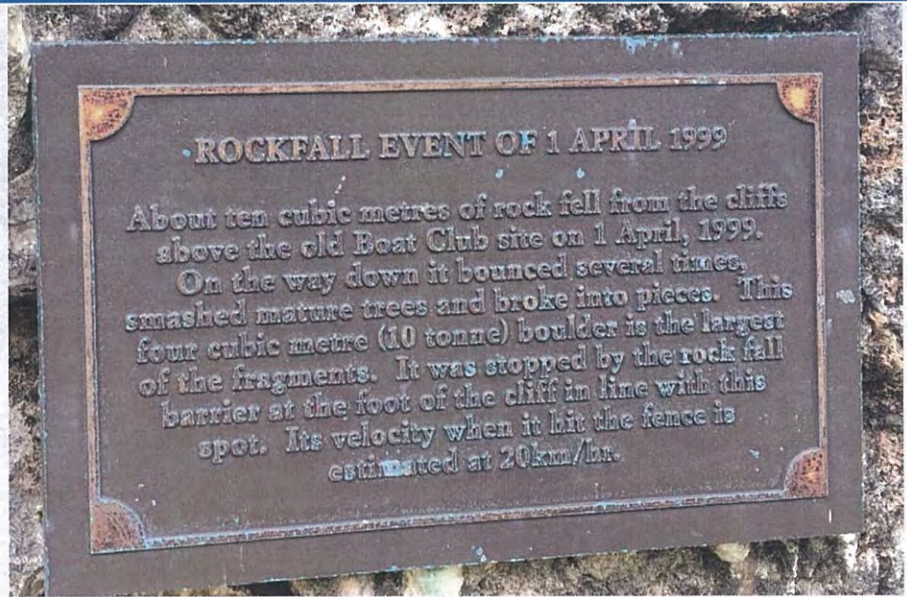
The largest of the boulders, approximately 6m<sup>3</sup>, came to rest on the road.



View of the large boulders reaching the shoreline

Date	Description
	
	<p>View of the destroyed barbecue area, note the large boulders and debris at the toe of the slope.</p> <p>Subsequent to this fall, a rockfall protection fence was erected in 1975 in the vicinity of the Boat Club and Marine Department buildings, consisting of untreated and welded rail steel, approximately 2m high (Golder, 1992). The fence was erected just up slope of the toe, approximately 2m high.</p>
1983/84	<p>Boat Club roof damaged by rockfalls, described in Golder, 1992. There is no further information as to the size and number of the rockfalls associated with this incident.</p>
1985	<p>A rockfall event behind the Kampong Area (potentially upslope of fence 408), resulted in rocks reaching the road close to the former housing blocks, damaging parked cars.</p> <p>Mesh rockfall fencing, approximately 1.8m high, was erected upslope of the Boat Club/Marine Building and a steel rockfall fence erected behind the Kampong area (exact location unconfirmed).</p>
1992 February/ March	<p>Boulders up to 0.8m<sup>3</sup> fall at the Boat Club site in February, hitting the road pavement.</p> <p>In March, boulders up to 1m<sup>3</sup> were recorded falling at the same site, coming to rest between the Boat Club and Fisherman's Landing Restaurant, damaging a sewer pipe.</p> <p>Of note is the fact that these two incidents resulted in material passing the previously installed rockfall fencing. However, no information suggests whether these falls bounced or passed through the fence.</p>
1995 February	<p>A boulder, approximately 12m<sup>3</sup>, fell from behind building 403, onto the railway cutting above. The boulder came to rest on the edge of the cutting above the workshop building, however, there was no record of damage to property.</p>
1999 1 April	<p>A rockfall behind the Boat Club, totalling 10m<sup>3</sup>, was observed by a passer-by. The rockfall consisted of a possible singular block of rock from the mid-section of the slope, which broke up during travel. The rock was described as breaking up on its way down the slope. The records indicate that a single boulder, approximately 4m<sup>3</sup> in size, was caught by the rockfall fencing installed behind the Boat Club building.</p>

Date	Description
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The record of this rockfall is presented on a plaque attached to a large boulder adjacent to the beach, at the site of the former Boat Club buildings. The information suggests that the boulder removed from the fence was estimated as 4m<sup>3</sup>. The plaque is attached to a boulder estimated to be less than half the size of that described. It is possible that the boulder may have broken up on moving, subsequently degraded or was grossly over estimated on recording.



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Date	Description
2007 24 October	A single 1m <sup>3</sup> boulder was observed to have reached and damaged the rockfall protection fence 408.
2014 23 March	A debris slide, known as the "Madrasa Landslide" is believed to have occurred following the Cyclone Gillian weather event. The slide was observed above the CI Club fence, with approximately 110m <sup>3</sup> of material coming to rest behind the fence.
	<div> </div> <div> </div> <p>Photographs showing the extent of the "Madrasa Landslide" zone of depletion (left) and accumulation within the protection fence (right) (Bowden, 2014)</p> <p>Following the same weather event significant volumes of fine soil 'washouts' were observed behind the AFP building, Marine Building and within the Boat Ramp area. No information has been provided as to the volume of these washouts, however, no damage was reported associated with these incidents.</p> <p>Very little is known as to the intensity of the rainfall related to Cyclone Gillian, with the island weather station at the airport malfunctioning prior to the weather system passing the island. Prior to the weather station fault, 181mm of rain in 24 hours were recorded by the Bureau of Meterology.</p>
2016 14 October	Three separate slides were observed to have occurred reaching the rockfall fences, following an intense period of rainfall. These slides have been recorded as the "Basketball Court Landslide", the "412 Landslide" and the "Boat Club Landslide".
	<p><b>Basketball Court Landslide</b></p> <p>The "Basketball Court Landslide" debris slide was observed above rockfall fences 408 and 412A. The landslide was assessed to involve upwards of 1,250m<sup>3</sup> of material (based on the recorded landslide scarp data), however, only approximately 27m<sup>3</sup> was calculated to have reached the fence locations, indicating 97% of the material came to rest on the slope.</p> <p>Evidence of the size and volume of the landslide can be seen in the following photographs, reproduced from Bowden 2016.</p>

Date	Description
	

View of the Basketball Court Landslide from the Kampong Settlement (left) and debris accumulated on the slope (right).

#### **412 Landslide**

The 412 Landslide was recorded as a narrow debris flow, commencing high on the slope above the 412 fence. The slide depletion zone indicates a total volume of material of approximately 40m<sup>3</sup>, however, only 25% of this material is calculated as reaching the 412 rockfall protection fence.

#### **Boat Club Landslide**

The Boat Club Landslide was assessed to have started at the cliff close to the Territory Day Park, high above the shore line. The landslide depletion area at the crown is calculated to consist of approximately 15m<sup>3</sup>, however, measurements of the accumulation at the slope toe indicate a volume of approximately 465m<sup>3</sup>. Approximately 10% of the material at the toe was captured by the rockfall fence, with the remainder passing, and coming to rest in the car park area. The fence was toppled by the debris material, including knocking flat of two fence posts.

Photographs of the landslide, reproduced from Bowden, 2016, are presented below.

Date	Description
	 <p>Debris accumulation within the Boat Club car parking area.</p>
	 <p>Zone of depletion below the Territory Day Park. Note the bedrock exposure and talus remnants on slope.</p>
<p>2017 1 June</p>	<p>A weather event between 31 May and 2 June 2017 resulted in approximately 300mm of rain falling at the Christmas Island Airport rain gauge. During this event, triggering Alarm Level 1, three landslides were observed. Two small landslides behind the CI Club and 412A/B fence. The debris slide behind the CI Club was assessed as containing approximately 20m<sup>3</sup> of material, stopping short of the rockfall fence. The debris slide upslope of fences 412A/B reached the fence, assessed to contain approximately 3m<sup>3</sup> of material.</p> <p>A larger debris slide at the site of the Boat Club rockfall protection fence destroyed the fence, with approximately 2,000m<sup>3</sup> of material. It is estimated that approximately 700m<sup>3</sup> of the landslide debris came to rest in the Boat Club car parking area. The landslide engulfed a parked car, extended approximately 20m beyond the fenceline.</p>

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Date	Description
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The following photographs of the landslide debris are reproduced from Bowden, 2017.




Debris within the Boat Club car parking area (source: Lisa Preston, Facebook).



Boat Club landslide debris captured at fence line

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Date	Description
	

View from above the destroyed Boat Club fence.

The regular monitoring of the condition of the landslide protection fences and the hazard mapping of the cove slopes has identified numerous smaller slides and isolated rockfalls. The records indicate that whilst the larger volume debris slides typically reach, or at times pass, the fence lines, much of the debris remains on the escarpment slopes. In fact, during the recent landslides in 2016 and 2017, only the landslides within the Boat Club fence area were observed to accumulate material greater than the volume assessed from measurements of the slide crown.

The information suggests that where debris slides occur at alternative locations across the cove the travel distance of the great majority of the debris remains on the slope as talus.

The monitoring of the protection fences has identified that isolated rockfalls of typically less than  $0.2\text{m}^3$  are common. Of the 195 individual rocks recorded by the regular fence monitoring, approximately 65% reached the toe of the slope but not the fence, with the remainder reaching the fence but not passing through.

There is no evidence to suggest that rockfalls have breached the rockfall fences following their installation.

GHD has been provided with a number of databases in Geographical Information System (GIS) and spreadsheet format. We have reviewed the spreadsheet data, which includes both a record of the rockfalls and debris slides reaching and passing the rockfall fences, but also a record of rock and debris flows and slides on the slope. We have reviewed the accuracy of this data, including the calculation of landslide volumes, position and date. Additionally, we have included information relating to the reach distance of the landslide, related to each rockfall fence. Information that could not be confirmed through reviewing the supplied literature or is outside the subject area has been removed from the inventory. Additional data, related to rockfalls and debris slides not previously recorded, has been added to the inventory in an attempt to provide a comprehensive record of the reported landslides within Flying Fish Cove. For the purposes of the risk assessment (i.e. this study), we have removed data from the inventory relating to rockfalls and landslides that did not reach the vicinity of the rockfall fences. The landslide inventory is reproduced in Appendix B.

# 10. Existing Landslide Mitigation Measures

## 10.1 History

Following the 1995 risk assessment a range of risk reduction strategies were submitted to the Parliamentary Joint Committee on Public Works and the chosen strategy was embodied in the RRMP. These strategies included:

- The construction of personnel fences and the erection of warning signs to limit access to areas deemed to be at risk.
- The construction of rockfall barriers in the areas of greatest risk, behind Blocks 408,412 and the Boat Club.
- Demolition of Blocks 408, 412 and the Boat Club to limit population exposure to landslide hazards, changes to work practices in the Marine Building to reduce occupancy, and plans to limit access to the foreshore during periods of high risk.
- The installation of warning mechanisms leading to responses at times of greater risk based on rainfall monitoring.
- Planting of Ficus trees on the slopes to create a vegetation barrier in the long term.
- The adoption of a RRMP.

## 10.2 Rockfall Barriers

As discussed above the rockfall barriers (sometimes referred to in previous reports as 'fences') were reported to have initially been constructed barriers in the areas of greatest risk, behind Blocks 408,412 and the Boat Club. This is reported to have occurred between 1995 and 1999. At some point after 2000 the barriers were extended across the full length of the site and now comprise series of barriers between the 'Boat Club Area' and the former Christmas Island Club. The barriers are named after nearby structures:

- Christmas Island Club Fence
- Building 408 Fence
- Building 412A Fence
- Building 412B Fence
- Marine 1 Fence
- Marine 2 Fence
- Boat Club Fence

The fences comprise 4m high flexible steel rockfall barriers designed and manufactured by Turbosider® (Figure 8). The drawings we have been provided state the capacity of the barrier is 1000 kJ. The reason this barrier capacity was selected is not clear, however the 1995 Golder report states that at the time the largest flexible barrier available at the time was in the order of 1000 kJ.

Turbosider® no longer supply or manufacture rockfall barriers and we are advised that Geobruigg Australia Pty Ltd (Geobruigg) has been supplying replacement parts to DIRDC to keep the barrier functioning for the last few years. Personal communications with representatives from Geobruigg Australia Pty Ltd indicate that the original rockfall fence tender (tendered in 1996) called for the supply of a 1000 kJ barrier.

A number of the previous reports state that the estimated design life of the barriers is 20 years.



**Figure 8. View of Rockfall Barrier behind the Marine 1 building**

### 10.3 Berms

The Baynes Geological report dated July 2000 recommended that a series of earth berms be constructed to provide additional long term protection from rockfall. The rationale was that the berms would be permanent features which would provide protection for the community should the rockfall barriers fail or be poorly maintained in the long term. A figure provided by DIRDC (presumed to have been once attached to the 2000 Baynes Geological report) shows that the berms were originally planned to extend across the whole length of the cove below the rockfall barriers.

The berms appears to have been constructed sometime between 2000 and 2003. For reasons not known, the recommended extent of the berms was not constructed. The berms were only constructed in the central area of the site below the 412B, 412A and 408 fences. Intriguingly, the 2003 GHD report contains a figure showing an earth berm located at the northern end of the cove behind Block 403, however this berm does not exist.

The 2000 Baynes Geological report only provided a concept sketch of a berm. The actual design, construction methods and energy absorbing capacity of the berms are not known. The berms observed on site at about 2m high with steeply sloping sides and completely covered by stone flagging as shown in (Figure 9).



**Figure 9. View of Berms Below 408 Fence**

#### **10.4 Trees**

One of the recommendations of the Parliamentary Joint Committee on Public Works was that *Ficus microcarpa* trees should be planted upslope from the rockfall barrier to provide extra protection in the longer term. This was repeated variously in many of the reports since this time however there appears to be little evidence other than 'hearsay' that this actually occurred.

Recent personal communications with Mr David Wagland of GHD and author the 1992 Golder Report indicates that at the time of his site visit, much the lower slopes of the escarpment were used for banana plantations.

At the time of our recent site visit the vegetation on the lower and upper slopes is essentially indistinguishable. It is not clear whether this is due to planning or natural re-growth.

# 11. Rainfall and Relationship to Landsliding

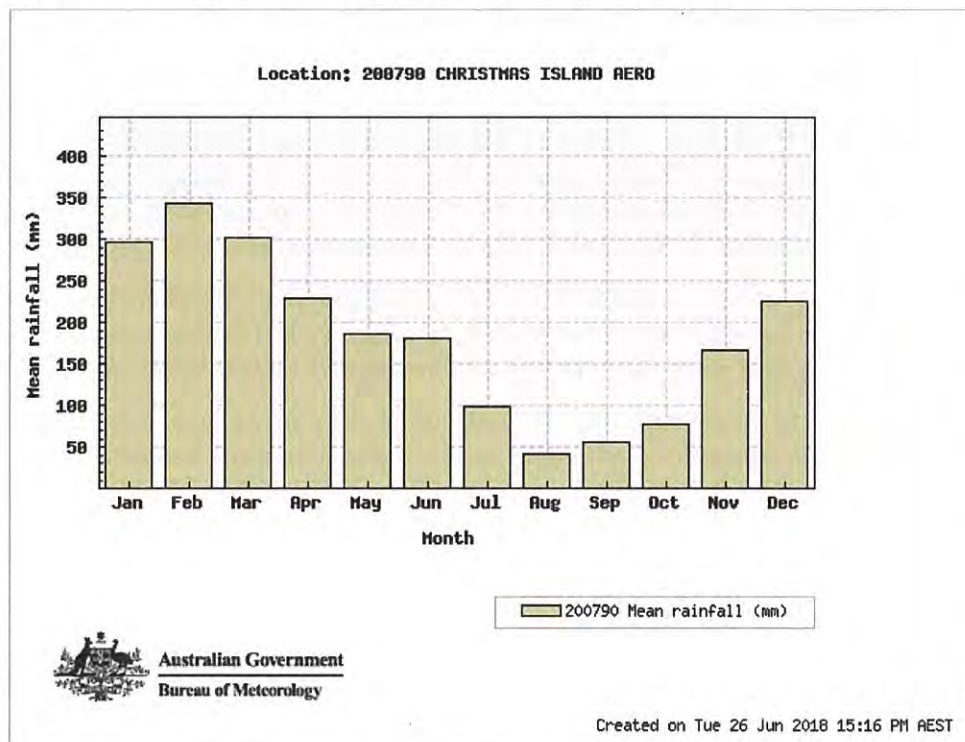
The rockfall risk management plan, implemented in 1997, includes a two tier warning system triggers based on rainfall data and key observation indicators. Daily rainfall data has been recorded on Christmas Island since 1901, with the data collected at the following Bureau of Meteorology weather stations:

- Station 200304 – Rocky Point – 1946 to 1973
- Station 200790 – Christmas Island Aero – 1972 onwards

Supplied information indicates that qualitative assessments of landslide incidents have been performed to attempt to derive a relationship with specific rainfall events. A loose relationship with falls/debris slides has been indicated through a general review of daily and monthly rainfall data.

The Flying Fish Cove Rockfall Risk Management Plan (RRMP) 2018 provides trigger levels of rainfall intensity, based on hourly and 24 hour periods, as an element of the overall landslide warning system. Level 1, Possible Indicators of Rockfall Event, is triggered whereby either greater than 52mm/hr or 163mm/24hr are observed. This rainfall intensity is described in the RRMP as a 1 in 5 year event. Level 2, Probable Indicators of Rockfall Events, is triggered by either greater than 113mm/hr or 356mm/24hr are observed. This rainfall intensity is described as a 1 in 50 year event.

Station 200790 has recorded a mean rainfall of 2,199mm/year, for the period between March 1973 and June 2018. Long term averages of rainfall at Christmas Island confirm highly seasonal rainfall periods, divided into a wet and dry season. The following graph of mean monthly rainfall is reproduced from the Bureau of Meteorology website (Figure 10).



**Figure 10. Christmas Island Mean Monthly Rainfall**

The historical frequency and duration of rainfall events at any given weather station is often presented graphically as an Intensity-Frequency-Duration (IFD) plot. IFD plots are often used to assess the intensity (i.e. 'heaviness') of rainfall events, and can be used to assess the influence of rainfall events on recorded landslides.

The probability that a given rainfall total accumulated over a given duration will be exceeded in any one year is defined as the Annual Exceedance Probability (AEP), which can be described as either a percentage or a "1 in x year event".

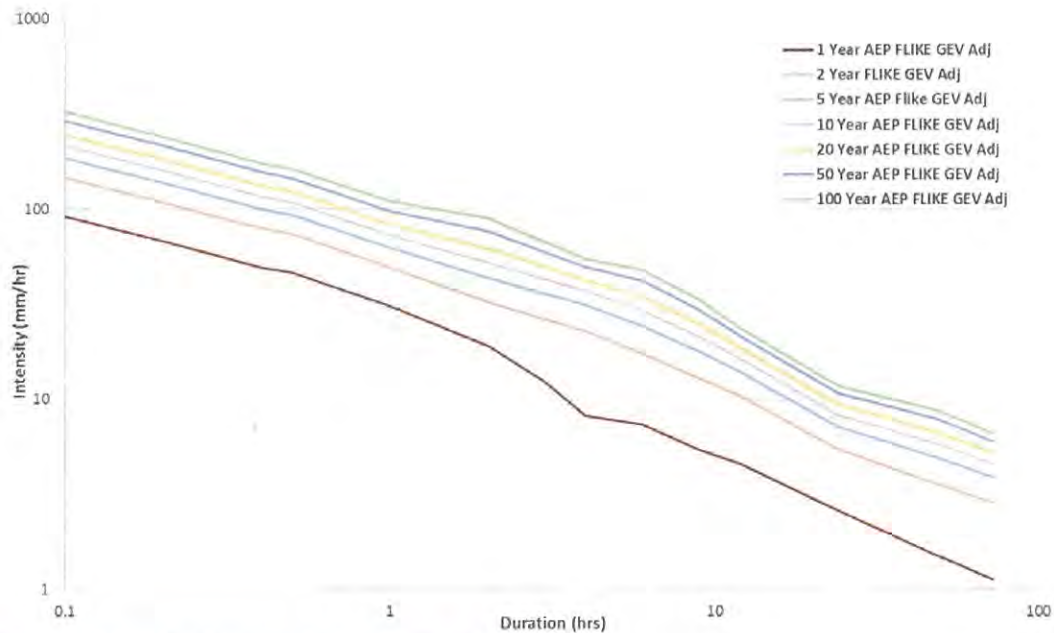
For rainfall triggered landslide events, the triggering rainfall is often presented as a relationship between intensity and duration. By plotting both the intensity and duration at varying AEP's it is possible to assess potential triggering thresholds for historical landslide events.

Typically the Bureau of Meteorology (BoM) produces IFD plots across Australia to assist in hydraulic design. These plots are based on grids of 0.025° latitude and longitude, approximately 2.8km<sup>2</sup> at the equator. At Christmas Island, however, the BoM does not produce such data, and thus we have developed IFD plots to assist in this landslide risk assessment.

The IFD data was developed from a combination of daily (44 years) and hourly (21 years) data recorded at the BoM Christmas Island Aero rainfall station to 26 May 2017. Frequency analysis of the data used a Generalised Extreme Value (GEV) distribution. The following limitations apply to the data:

- The sub-hour duration results produced using frequency analysis were assessed to be unreliable. An alternative approach was adopted, utilising the Darwin IFD plots, with the slope of each AEP curve for the 0.1 to 0.5 hour durations calculated and applied to the corresponding frequency analysis output at Christmas Island. It is noted that this method may not accurately represent true rainfall intensity for these durations on the island.
- Developing the IFD data from only one station is a potential limitation as it is not likely to be representative over the study area. IFD data in Australia is developed using a number of stations. This may be of particular importance given the evidence of spatial variation of rainfall from a previous GHD study. Applying this data across the catchments may still be conservative as it has been suggested that the Christmas Island Aero station has recorded higher rainfall than other areas. Future work should involve development of site-specific IFD data.
- The period of record used for the analysis is limited. The majority of the durations were produced using 21 years of data, which is lower than IFD data developed through the rest of Australia. This can be refined in the coming years as more data becomes available.

The following figure presents the IFD developed for Christmas Island, with the associated AEP curves plotted, representing an upward trend of more intense/less frequent events.



**Figure 11 – Christmas Island IFD Plot**

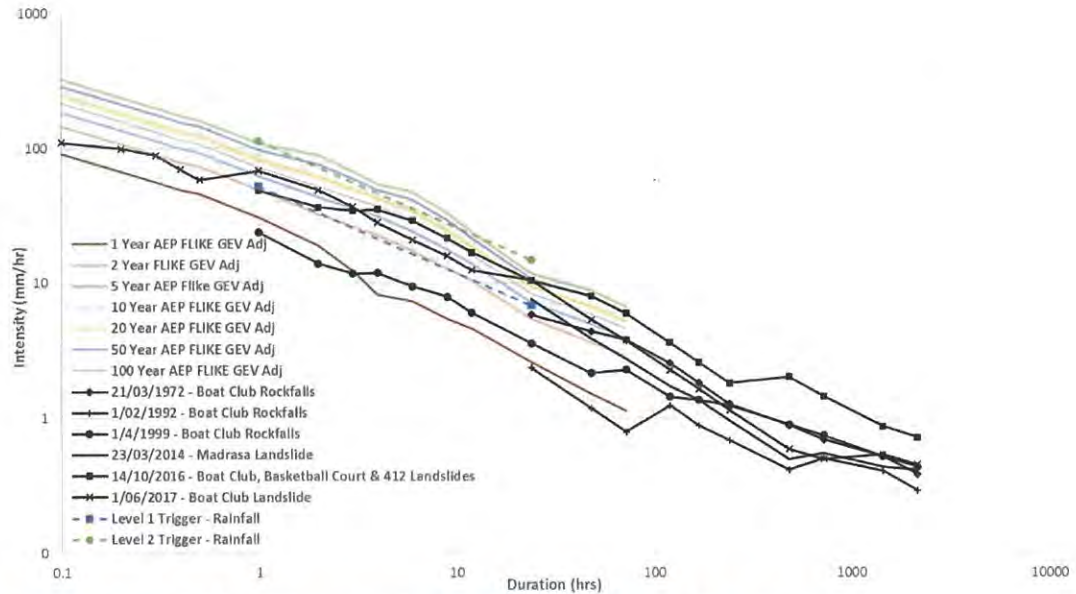
In the plot above the 1 Year AEP curve represents the cumulative rainfall intensity of a 1 in 1 year event at Christmas Island, or a 100% probability of exceedance each year. Furthermore, the 100 Year AEP curve represents a 1 in 100 year event, or a 0.1% probability of exceedance each year.

Short duration, high intensity rainfall events are typically assessed as key to the initiation and mobilisation of debris flows. However, defining the durations and intensities that may trigger such landslides is often difficult. In addition, rockfalls can be triggered by many mechanisms including rainfall, such as rock mass failure, vegetation, wind, earthquakes etc.

The precise timing of landslide events within Flying Fish Cove are generally not known, with the 2017 Boat Club landslide event the most accurately known to within about 30 minutes. All data supplied by the BoM is provided in daily records, therefore, assessment of landslides correlating to sub-24 hour rainfall events is not possible.

A review of the longer term rainfall events at times close to known debris slides and larger rockfall events has been performed. The review has chosen landslide events of sufficient size to have been accurately recorded and for which sufficient detail of timing is known. Whilst the "Madrasa" landslide is shown on the following plot, care should be taken with the data used in this event. This landslide was recorded during or shortly after Tropical Cyclone Gillian passed Christmas Island on 22 March 2014. During this time the BoM weather station was malfunctioning, and the daily record of 181mm in the 24 hours to 9am on 22 March 2014 is provided only in the BoM cyclone record ([www.bom.gov.au](http://www.bom.gov.au)). Rainfall records prior to this known malfunction must therefore, be used with caution.

The rainfall intensity at, or close to the event, between one and 90 days has been plotted with the IFD curves, as shown in the following figure.



**Figure 12 –Rainfall Intensity during Major Landslide Events**

The data indicates that of two of the recorded debris slides for which rainfall data is held, i.e. events in 2014 and 2017, the associated 1 to 5 day rainfall intensity generally fall within the 2 year AEP curves, representing a 50% probability of exceedance in one year. As the 2014 event is known to have occurred during the rainfall gauge malfunction, this event may represent a higher AEP than that shown.

The rainfall event associated with the 14 October 2016 landslides has a 5 to 10 day duration approximately matching the 50 Year AEP, representing a 2% probability of annual exceedance. This type of event is typically described as a rare event.

Whilst rockfalls are typically not solely associated with rainfall events, as the timing of these events are known to some degree of accuracy, three events, in 1972, 1992 and 1999 are plotted on the IFD curves, above. The rainfall associated with these three events indicate they occurred in periods of below a 1 year AEP to approximately a 5 year AEP.

Rainfall intensity values for both Level 1 and Level 2 triggers are plotted on the curves presented in Figure 12. The information suggests that the all major, recorded rockfalls have occurred during rainfall periods below the Level 1 trigger.

Of interest is that of all the recorded major landslides, not one occurred during a rainfall event exceeding the Level 2 threshold. It must be noted, however, that the event following Cyclone Gillian may have exceeded this threshold but, due to the malfunctioning equipment, no accurate record of rainfall can be made.

The data suggests that debris slides of 2016 and 2017 occurred during a rainfall event above the Level 1 hourly and 24 hour threshold.

All rockfalls, where rainfall data is available, occurred below the Level 1 thresholds.

## 12. Seismicity

Strong earthquake ground motion generally increases the likelihood of landslides in susceptible landscapes. The report by Andrews (1900) suggested that an earthquake in 1895 resulted in large rockfalls from the Flying Fish Cove slopes.

Reporting by Golder (1995) provided relatively detailed analysis of the seismicity of the Christmas Island locale, suggesting a probability of earthquakes in the region.

Seismic events are classified as a trigger of Level 1 and 2 warnings within the current Rockfall Risk Management Plan (2018). The RRMP indicates that a Level 1 warning is triggered during a seismic event of intensity IV or V on the Modified Mercalli (MM) Scale. Level 2 warning is triggered following an earthquake of greater than MMV intensity at Flying Fish Cove.

Whilst an attempt was made by Guria Consulting, in Golder (1995), to provide relationships of earthquake magnitude and intensity, the reporting indicated that this was draft, and based on limited data. Whilst subsequent five year reviews, completed in 2006 and 2011, provide further analysis of the likely return periods and magnitudes of earthquakes in the region, there is no further research into the measurement of intensity records on the island. Additionally, recommendations within the 2006 5-year review suggest that the RRMP trigger levels be updated to reflect accessible data related to magnitude, distance from Flying Fish Cove and depth of earthquake. The recommendations do not appear to have been incorporated into later revisions of the RRMP.

Review and monitoring of earthquake magnitudes within a 500km of Christmas Island has been presented in the annual inspection reports and the five year review documents supplied, suggesting little correlation. However, without correlating these events to intensity, in MM, felt in Flying Fish Cove, it is not appropriate to attempt to assess the appropriateness of the warning thresholds. Performing such a review is outside the scope of this assessment, and will require specialist seismic engineering advice. Given that apart from the uncertain report from 1900 there has been no conclusive correlation between earthquakes and rockfalls and there is also no means of directly measuring earthquake intensity on the island, the time and effort devoted to assessing seismicity over the last 20 or so year is of questionable value.

## 13. Preliminary Rockfall Modelling

In order to assess the behaviour of falling rocks and inform the risk assessment, rockfall modelling was carried out using the commercially available software RocFall™ V6.002 produced by Rocscience Inc. RocFall is a 2-dimensional rockfall simulation program for the prediction of rockfall behaviour on slopes. The purpose of the modelling was to:

- Estimate the kinetic energy associated with rockfalls reaching the rockfall barriers
- Estimate the travel / run-out distance of rockfalls
- Estimate potential rockfall bounce heights

Initially we 'back-analysed' the 1999 rockfall event at the Boat Club area in order to validate the parameters used for the modelling (coefficients of normal and tangential restitution and others). The analyses modelled a block of rock with a mass of 10 tons, which is the mass reported for the 1999 rockfall. A rock of this mass would have a volume of between about 3m<sup>3</sup> and 4m<sup>3</sup> (i.e. Medium size) and could be expected to have dimensions of about 2 m x 1.5 m x 1 m. The model successfully predicted the reported runout distances of the rocks associated with the 1999 rockfall as well as those of the 1972 rockfall that also occurred at this location.

The slope profiles used in the modelling are the same as those presented as cross sections A to F (Figures A4 to A9). The same sized rock was arbitrarily used for the rockfall modelling at each of the cross sections. Between 1,000 and 1,500 rockfalls were modelled at each section. Rockfall statistics modelled where each section line intersects the rockfall barriers are summarised in Table 4 and the rockfall model outputs are presented in Appendix C.

**Table 4. Summary of Rockfall Modelling at Rockfall Barriers**

	Section A	Section B	Section C	Section D	Section E
Minimum energy (kJ)	1	6	73	31	7
Maximum energy (kJ)	3476	6230	4019	1681	863
Mean energy (kJ)	1032	1098	977	772	280
Median energy (kJ)	961	910	789	768	233
% rocks reaching rockfall barrier	44	44	15	4	6
Mean bounce height (m)	2.9	2.7	2.8	3.0	1.7
Maximum bounce height (m)	10.0	11.8	7.6	8.6	6.8

*Note: Rockfalls modelled originating from natural cliffs above railway cutting on Section F do not reach rockfall barrier location.*

The same rockfall models were used to assess the behaviour of rocks once they reach the berm locations at Sections C and D. The results are presented in Table 5.

**Table 5. Summary of Rockfall Modelling at Berms**

	Section C	Section D
Minimum energy (kJ)	5	23
Maximum energy (kJ)	2361	1169
Mean energy (kJ)	508	424
Median energy (kJ)	384	361
% rocks reaching rockfall barrier	9	2
Mean bounce height (m)	2.7	2.3
Maximum bounce height (m)	8.6	5.4

Unsurprisingly there is a large scatter in the data, particularly in regards to rockfall energies. This is to be expected given the slopes above the rockfall barriers are predominantly talus slopes and a large proportion of rocks that detach from the cliff faces accumulate on the slopes prior to reaching the barriers.

Interestingly, both the mean and medium energies associated with the modelling of the 1999 rockfall event are in the order of 1000kJ. This probably explains why the rock was caught by the barrier.

In addition to mass, the kinetic energy associated with a falling rock is affected by many factors that alter the speed of the rock such as the source location, slope roughness, slope material, vegetation, fragmentation and the fall path. For this reason it is not appropriate to report a maximum rock size that the rockfall barriers are likely to catch. However, given that the mean energies modelled for Sections A, B and C are all in the order of 1000kJ with the maximum modelled energies in some cases significantly higher, it is considered unlikely that the rockfall barriers could catch rocks larger than the size that was modelled.

The energy absorbing capacity of the berms is not known, however we envisage it is significantly higher than the rockfall barrier. Based on the modelling, the berms would likely catch Medium rockfalls similar in size to the 1999 and 1972 events, although they would likely sustain severe damage and would require repairs or re-building.

The maximum rockfall runout distances (assuming the rockfall fence is breached) can be seen in the rockfall model outputs presented in Appendix C and are briefly summarised below:

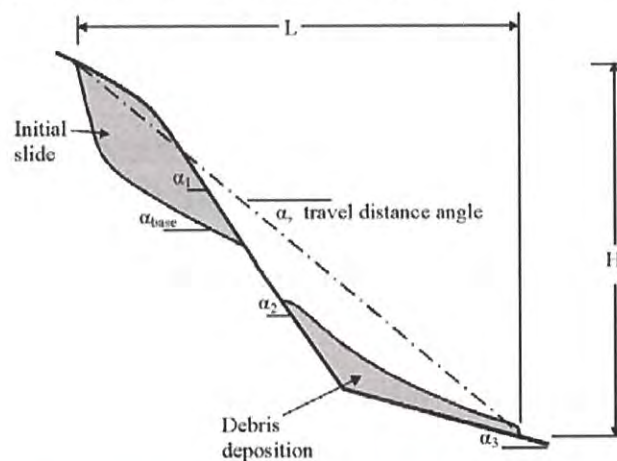
- **Section A (Boat Club Area)** – Rocks reach car park area and the sea / foreshore.
- **Section B (Marine Building Area)** – Rocks reach as far as the sea / foreshore.
- **Section C (Block 413 Area)** – Rocks may reach the rear of Block 413, however this is considered unlikely as they are likely to be caught by the berm.
- **Section D (Block 409 Area)** – Rocks may reach the storage sheds at the rear of Block 409, however this is considered unlikely as they are likely to be caught by the berm.
- **Section E (Madrasa / Shop Area)** – Rocks may reach the Madrasa Building and shop.
- **Section F (Block 403 Area)** – Majority of rocks from natural slopes are unlikely to reach rockfall barrier.

As mentioned above, the rockfall modelling suggests the majority of rockfalls originating from natural slopes at Section F are very unlikely to reach the toe of the slope. This appears to be due to the gentler talus slopes in this area. Based on our observations, the rockfalls recorded during monthly and annual inspections along the railway line in this area likely originate from the adjacent railway cutting.

# 14. Landslide travel distance assessment

## 14.1 Travel Distance Estimation

To assess risk posed by landsliding it is necessary to estimate whether landslides will travel to the elements at risk (i.e. people and property). We have carried out an assessment of landslide travel distance by reviewing the landslide data mapped by Bowden Geologic between 2014 and 2017 as well as by applying methods outlined by Hunter and Fell (2002). The latter is an empirical method that uses knowledge of the slope geometry, landslide mechanism and soil type to predict travel distance. The method was developed by analysis of a large database of landslides. The terms used in this assessment are summarised in Figure 13. In using this method, we have assumed that the rockfall barriers will fail under the impact of debris associated with Very Large and Extremely Large landslides, as was experienced in 2017 and 2017 at the Boat Club.



**Figure 13. Definition of travel distance,  $L$ , height,  $H$ , travel distance angle,  $\alpha_1$ , downslope angle,  $\alpha_2$ , distal downslope angle,  $\alpha_3$ .**

The 2017 Bowden Geologic report summarised the Travel Distance Angles for the landslides that occurred in 2014, 2016 and 2017. These are presented in Table 6.

**Table 6. Summary of Travel Distance Angles for 2014, 2016 and 2017 Landslides**

Location	Year	Landslide Type	Travel Distance Angle
Boat Club	2017	Channelised debris flow	28°
Boat Club	2016	Debris flow	31°
412B	2016	Debris flow	32°
412A	2016	Debris flow	33°
408	2016	Debris flow in fill	42° (uncertain)
CI Club	2014	Debris slide	28°

A summary of the landslide travel distance angles estimated using the Hunter and Fell (2002) method are presented in Table 7 below.

**Table 7. Estimated Landslide Travel Distance Angles**

Downslope angle, $\alpha_2$	Landslide Type	Travel Distance Angle	Comments
33°	Debris flow (with partly confined travel path)	28°	Applicable to talus slopes across the lower half to two thirds of the escarpment with shallow gullies
33°	Debris flow (with unconfined travel path)	31°	Applicable to talus slopes across the lower half to two thirds of the escarpment without gullies
36°	Debris flow (with partly confined travel path)	30°	Applicable to steeper talus slopes across the upper sections of the escarpment with shallow gullies
36°	Debris flow (with unconfined travel path)	33°	Applicable to steeper talus slopes across the upper sections of the escarpment without gullies

As is demonstrated by the results in Table 7, there is very good agreement between the observed landslide travel distance angles and the predicted values. This study has adopted travel distance angles of either 28° or 33° depending on the slope morphology. These angles have been annotated onto each of the cross sections presented in Figures A4 to A9 to assess the landslide travel (i.e. 'runout') distance. In addition, the observed landslide travel distances for both the 'Boat Club' landslide that occurred in 2016 and 2017 are shown on Section A in Figure A4.

Unsurprisingly, debris flows that may occur in the vicinity of the 'Boat Club' area are predicted to travel into the car park and the vicinity of the shoreline as was the case in 2016 and 2017. Similarly, debris flows that originate above the adjacent Marine 1 building are predicted to have a similar travel distance and would likely reach Jalan Pantai Road or the shoreline (i.e. impact the Marine Building).

Debris flows originating on the slopes above the Madrasa and adjacent grocery shop also have the potential to reach these buildings as there are no protective berms constructed above these structures. There are also no protective berms above Block 403 and the assessment suggests debris flow could reach the vicinity of the rear of the building.

#### 14.2 Preliminary Assessment of Berm Capacity

The landslide travel distance estimation methods described above cannot account for the presence of the man-made structures such as the berms and modified topography associated with the former phosphate loading area above Berm 1. We have therefore carried out preliminary three-dimensional volume calculations to assess the potential of these areas to contain landslide debris.

This assessment has been carried out to inform the landslide risk assessment and is approximate. It must be pointed out that the berms have not been surveyed and survey point cloud data for all structures in the Kampong appears to have been stripped out of the LiDAR data provided. Consequently we manually approximated the berm geometry in a 3D drafting software package that was used for the volume estimation. It should also be pointed out that we have assumed the berms will not be overturned by the impact force of the landslides.

For the volume estimation we have assumed that landslide debris will accumulate to the full height of the berms, with the backfilled debris sloping at an angle of about 10° (relative to the horizontal) downslope. The 10° is considered conservative given the coarse nature of the landslide debris. A similar approach was used to assess the capacity of the large benched area at the former phosphate loading area above Berm 1 and we have assumed material will accumulate across the full width of the bench.

The total capacity of Berm 1, which is relatively short (about 38m), was estimated to be about 800m<sup>3</sup>. The potential catch volume of the large benched area at the former phosphate loading area is estimated to be at least 2,000m<sup>3</sup>. Given that recent Very Large landslides such as the 2017 Boat Club Landslide had total volumes estimated to be about 2,000m<sup>3</sup> (of which only about 700m<sup>3</sup> reached the toe of the slope), it is considered very unlikely that landslides originating above Berm 1 will breach the berm.

The volume of Berm 2, which is considerably longer, was estimated to be between approximately 700 m<sup>3</sup> and 1000 m<sup>3</sup> for each 20 m section of its length. Should a narrow, Very Large or Extremely Large landslide occur upslope of this berm, the debris may not spread out sufficiently behind the berm, resulting in the debris overtopping. This could result in debris spreading out across the carpark and it may impact the storage sheds behind block 413.

# 15. Landslide Hazards and Processes

## 15.1 Introduction

Although this report has discussed the history of major landslide events and probable travel characteristics, we consider it important to highlight the two main hazards associated with landsliding in Flying Fish Cove as these will be considered in the QRA later in this report.

## 15.2 Rockfalls

Rockfalls in the cove originate from three sources:

- Rock masses detaching from the cliffs towards the upper sections of the escarpment
- Talus that is remobilised and travels downslope
- Rockfalls from the man-made railway cutting in the northern area of the site

Firstly, the rockfalls that originate from the railway cutting are of little concern because these were observed to accumulate in talus cones at the toe of the cut or come to rest on the flat bench adjacent to the rockfall fence. It should be pointed out that the monthly rockfall inspections and annual reports have not differentiated these rockfalls from the rockfalls originating from natural slopes. As discussed above, the rockfall modelling suggests it is very unlikely rockfalls from natural slopes can reach the toe of the escarpment in this area due to the gentler slopes. We therefore consider that most, if not all of the rockfalls that have been recorded in this area originate from the adjacent cutting.

Rockfalls originating from the cliffs on the escarpment could be triggered by a number of processes such as root-jacking, wind induced movements associated with trees growing on the cliffs, seismic activity, gradual erosion / weathering of underlying rock, softening and/or expansion of clay infilled rock defects and elevated pore pressures due to rainfall. Upon detachment, rocks travel downslope and are deposited on the slopes as talus. This is the natural process by which such escarpments evolve and regress inland. The majority of rockfalls come to rest on the talus slopes and it is impossible to predict whether a specific rock, once detached will travel all the way the toe of the slope. This is also indicated by the rockfall modelling.

Rockfalls may also originate from talus that becomes mobilised. This could be triggered by mechanisms such as localised slumping and tree movements.

The landslide inventory indicates rockfalls reaching or passing the vicinity of rockfall fence are distributed across the full length of the cove. However, as discussed above we consider that the rockfall records in the northern area of the site (i.e. at Section F, Figure A9) are misleading due to the proximity of the railway cutting. Apart from this area there is little evidence in the inventory to suggest rockfalls occur more frequently in certain locations. Given the history of rockfall events at the Boat Club area there is a possibility that rockfalls may be more frequent and larger here, however this is based on a small number of reports in an area where rockfalls are more likely to have been noticed.

### 15.3 Debris Flows

Debris flow hazards received relatively little, if any attention in early geotechnical studies carried out at the site. The reason for this not clear, but may be because the details of the 1935 debris flow event were not known at the time and local memory of this event or other similar events had been lost or forgotten. As a result, debris flow hazards are not given appropriate attention in the RRMP.

The nature of the debris flows that have been observed at the site have been described in detail above. The flows typically comprise mobilised talus material predominantly comprising coarse rock material as well as varying proportions of fine colluvial soil (clays and silts).

The mapped debris flows typically originate on the mid and upper escarpment slopes and are triggered by intense rainfall as discussed in Section 11. Based on the landslide inventory and topography that has few well defined gullies, debris flow could occur anywhere across the escarpment. Very Large and Extremely Large debris flows are expected to breach the rockfall barriers. However, as described in Section 14.2, the man-made benched area at the former phosphate loading area above Berm 1 will greatly reduce the potential for debris flows to reach the toe of the escarpment.

### 15.4 Landslide Volume Frequency Model

A summary of major documented landslides which reached the toe of the escarpment or the vicinity of the rockfall barriers is given in Section 9 and the associated landslide inventory for all documented events is included in Appendix B. As discussed in Section 8, volume terms have been adopted ranging from Very Small to Extremely Large in order of magnitude categories. The estimated volume of debris reaching or passing the vicinity of the rockfall barriers for each of the known landslides has been based on previous mapping and reports or estimated based on descriptions or photographs.

Records of past landslides can provide some information on what has happened but are invariably incomplete. For example, the living memory of the 1935 landslide event (assessed as an Extremely Large event) appears to have been misrepresented in earlier reporting, with Golder (1995) potentially recording it as an isolated event that damaged a house in the 1930's. The reports prepared during the 1990's also recount stories of rockfalls told by local residents however the details are not known. These are also likely to have been large rockfalls because small events are likely to have gone unnoticed.

For the purposes of the QRA, we have developed a landslide volume frequency model (Figure 14) which predicts the long term average number and volume of landslides reaching the toe of the escarpment per year. The approach to developing and using landslide volume frequency models is given in Moon et. al (2005). The Flying Fish Cove model is based on knowledge and interpretation of evidence on:

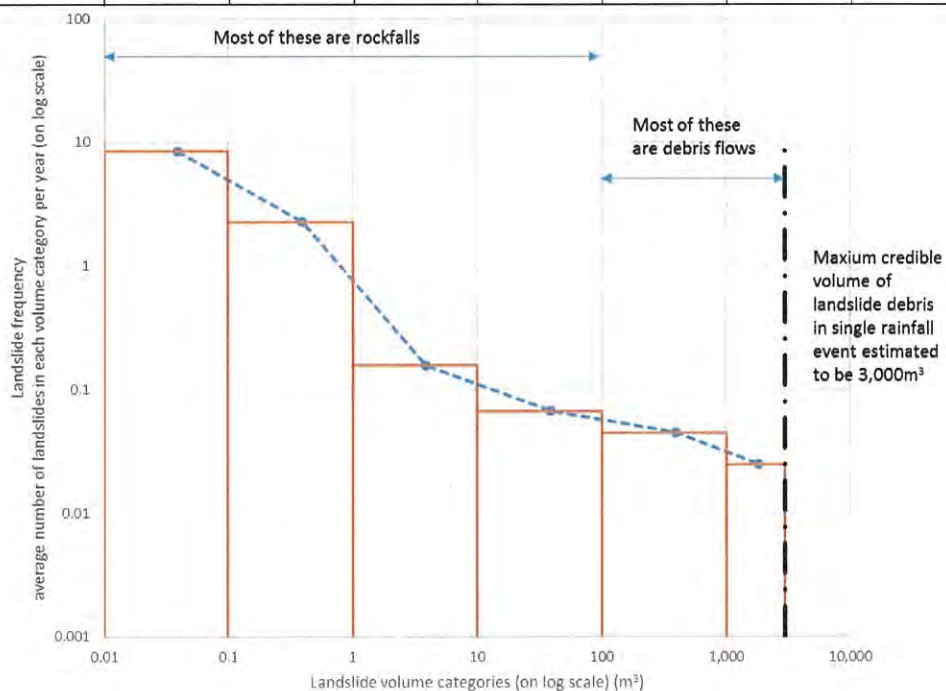
- The geomorphological history of the region.
- Landslide failure mechanisms in general, and
- The documented landslides in the landslide inventory.

In developing the Flying Fish Cove landslide model we have made the following assumptions:

- The average recurrence interval (ARI) for Extremely Large Debris Flows is 0.025 (1 in 40 years). This is based there being two known events in a period of about 75 years and the assumption that the historic record for Extremely Large landslides is complete, i.e. that any such landslides that have occurred in this period will have been recorded.

- It is possible that larger debris flows could result in more than 2,000 m<sup>3</sup> of debris reaching the toe of the escarpment in a single storm event and the maximum credible volume is likely to be about 3,000 m<sup>3</sup>.
- Rockfalls within the Medium category are recorded as events typically consisting of multiple, smaller rockfalls. A total of seven of such events have been recorded between 1972 and 2017, indicating a typical return period of a little over six years.
- The ARI for Large rockfalls is 0.067 (1 in 15 years). This assessment is based on three Large events between 1972 and 2017. These Large events are all recorded as rockfall events.
- Very Large events have been calculated as having a return period of approximately 23 years (ARI of 0.044). However, this is calculated on the volume of just two debris slide events of recent years, the 2014 Madrasa and 2016 Basketball Court landslides, reaching the rockfall barriers.
- We have assumed that Large and Very Large events following the documented 1972 event have been recorded and included in the landslide inventory. It is possible that a number of Large and Very Large events occurred prior to 1972, however, no accurate records have been found to substantiate potential falls. The recent 2014 and 2016 debris landslides demonstrate that like many other natural hazards, these events are not evenly distributed in time.
- Under present conditions, about 11 rockfalls per year in the range Very Small to Small reach the rockfall barriers.
- The long term average annual volume of material reaching the toe of the escarpment is about 67 m<sup>3</sup>.

Average landslides per year	Very small	Small	Medium	Large	Very large	Extremely large	Totals
Volume (m <sup>3</sup> )	0.33	0.89	0.61	2.6	17.4	45.0	66.7
Number	8.4	2.3	0.16	0.07	0.04	0.025	11 landslides



**Figure 14. Landslide Volume Frequency Model**

# 16. Quantitative Landslide risk assessment

## 16.1 Background

When dealing with natural or man-made slopes it is industry practice to assess instability risks using methods consistent with the principles of the Australian Geomechanics Society's Practice Note Guidelines for Landslide Risk Management (AGS 2007c). The AGS (2007) guidelines provide a national framework for Landslide Risk Management and are widely used. This assessment has been carried out using methods consistent with the AGS guidelines.

The purpose of the risk to life assessment is to estimate the annual risk of 'loss of life' to an individual at the site. The individual is taken to be the 'person most at risk', who typically has the greatest exposure to the risks (i.e. greatest spatial temporal probability).

The risk of 'loss of life' to an individual is calculated from:

$$R_{(LoL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)}$$

Where:

$R_{(LoL)}$  is the risk (annual probability of death of an individual).

$P_{(H)}$  is the annual probability of the hazard occurring (event).

$P_{(S:H)}$  is the probability of spatial impact of the event impacting an individual taking into account the travel distance and travel direction given the event. For example, the probability of an individual in a vehicle, building or in the open being impacted by a landslide at a given location.

$P_{(T:S)}$  is the temporal spatial probability (e.g. of the building or location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the event occurrence.

$V_{(D:T)}$  is the vulnerability of the individual (probability of loss of life of the individual given the impact).

There are currently no legislated risk acceptance criteria for loss of life due to landslides in Australia and it is the responsibility of the property owner or managing authority to set the Tolerable Risk Criteria for loss of life. AGS (2007c) provides the following recommendations in relation to tolerable risk criteria for loss of life:

**Table 8 AGS 2007 Suggested Tolerable Loss of life Individual Risk.**

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope / Existing Development	$10^{-4}$ / annum
New Constructed Slope / New Development / Existing Landslide	$10^{-5}$ / annum

For the purposes of the QRA, the site has been divided into six areas centred around each of the cross sections presented in Figures A4 to A9. These areas along with the elements at risk in each area are summarised below:

**Table 9. Summary of Elements at Risk**

Area	Cross Section Reference	Elements at risk
Boat Club Area / carpark	Section A	Individuals in carpark (in open) Individuals in vehicle Vehicle driving along Jalan Pantai Road (north of traffic lights)
Marine Building	Section B	Individuals working in Marine Building Individuals working in Federal Police Building
Block 413 Area	Section C	Individuals in carpark (in open) west of Berm 2 Individuals in storage shed behind Block 413 Individuals on basketball court
Block 409 Area	Section D	Individuals in carpark (in open) west of Berm 1 Individuals in storage shed behind Block 409
Madrasa / Shop Area	Section E	Individuals in Madrasa Individuals in shop Individuals in cold storage building behind Madrasa
Block 403 Area	Section F	Individuals in carpark behind Block 403 Individuals in Block 403

## 16.2 Landslide Likelihood $P_{(H)}$

The event likelihoods (annual landslide probabilities) used in the QRA are typically as described in the landslide volume frequency model in Section 15.4. However, due to limited historic data in some areas of the site and the presence of man-made structures and landforms that affect the travel distance probability of some landslides, it has been necessary to adjust the annual likelihood of landslides in some instances. These adjustments have been based on the modelling discussed in this report and are summarised below:

- All Very Small and Small rockfalls will be caught by the rockfall barriers.
- Approximately 70% of Medium sized rockfalls are assumed to penetrate / breach the rockfall barriers and all Large sized rockfalls will breach the rockfall fence.
- Less than approximately 5% of rockfalls that occur where berms are present will breach the berms.
- Less than approximately 10% of rockfalls that occur at the northern end of the site above Block 403 are expected to travel as far as Block 403.

## 16.3 Temporal Probability $P_{(T;S)}$

The risk assessment process requires a number of judgements to be made, particularly in relation to individual's exposure to risks. The exposure of individuals to hazards in Flying Fish Cove has been based on information provided by DIRDC and our site observations. A summary of this information and the adopted temporal probabilities are presented in Table 10.

**Table 10. Summary of Temporal Probability Judgements**

Area	Elements at risk	DIRDC comments and GHD assumptions	Temporal Probability $P_{(T:S)}$
Boat Club Area / carpark	Individuals in carpark (in open)	On a typical day individuals may spend up to 2 hours in the carpark each day to retrieve / park cars.	0.0833
	Individuals in vehicle	Up to 10 cars parked in carpark during the day at any one time with up to 30 cars using the carpark during a typical weekday. On a weekend 15 cars may be parked during the day at any one time with up to a total of 50 cars throughout the day. We assumed the total time spent by an individual in a parked vehicle is about 7 hours / week.	0.0417
	Vehicle driving along Jalan Pantai Road (north of traffic lights)	Road is used by visitors to the Tai Jin House and staff travelling to the sewage facility and fuel farm. Up to 15 return trips each day.	0.0052
Marine Building	Individuals working in Marine Building	This building has offices and workshops and could have up to 4 to 5 people working about 40 hours each week.	0.2381
	Individuals working in Federal Police Building (boatshed)	Used three to four times each week for a few hours each visit (i.e. 3hrs x 4). Maintenance work takes an	0.1012

Area	Elements at risk	DIRDC comments and GHD assumptions	Temporal Probability P <sub>(T:S)</sub>
Block 413 Area	Individuals in carpark (in open) west of Berm 2	additional five hours on one day each week.	
	Individuals in storage shed behind Block 413	No people were observed in this area during our site visit. We have assumed an individual may spend on average up to 3 hours each week in this area.	0.0179
	Individuals on basketball court	We have assumed individuals may spend on average up to 2 hours each week retrieving / packing items in sheds.	0.0119
Block 409 Area	Individuals in carpark (in open) west of Berm 1	We have assumed individuals may spend on average up to 2 hours each week on the basketball court.	0.0119
	Individuals in storage shed behind Block 409	No people were observed in this area during our site visit. We have assumed an individual may spend on average up to 3 hours each week in this area.	0.0179
Madrasa / Shop Area	Individuals in Madrasa	The Madrasah is occupied during school terms between Monday and	0.0536

Area	Elements at risk	DIRDC comments and GHD assumptions	Temporal Probability P <sub>(T-S)</sub>
Block 403 Area		Thursday for about 2 hours each day. Functions are occasionally held (a few times each year).	
	Individuals in shop	We have assumed the shop is occupied for about 40 hours each week.	0.2381
	Individuals in cold storage building behind Madrasa	We have assumed individuals may spend up to 2 hours each week retrieving / packing goods in this building.	0.0119
	Individuals in carpark behind Block 403	We have assumed individuals may spend on average up to 2 hours each week in this area.	0.0119
	Individuals in Block 403	We have assumed building is occupied by people most of the time, however people are present on the ground floor about 50% of the time.	0.5

## 16.4 Vulnerability Assessment

AGS (2007c) publishes a range of vulnerability values for different scenarios that are based on published case studies. The values we have adopted for our analysis are based on these, our own judgements and the likely scenario should an element at risk be impacted by the hazard. The adopted values are presented in Table 11.

**Table 11. Adopted Vulnerability Values**

Scenario	Hazard	Comments	Adopted Vulnerability Value
Person in open space if struck by rockfall	Rockfall	Rockfalls that breach rockfall barriers will be large and travelling at high velocities. Chance of survival is low.	0.9
Person in vehicle if crushed by rockfall	Rockfall	Death is almost certain	1
Person in moving vehicle on Jalan Pantai Road if struck by rockfall while passing Boat Club area	Rockfall	Velocity of rocks will be reducing by this point (e.g. 1972 rockfall event). Chance of survival is higher than the carpark area.	0.5
Person in building if struck by rockfall	Rockfall	Buildings in Flying Fish Cove will offer little protection from large rockfalls	0.8
Person in open space if buried by debris	Debris Flow	Death by asphyxia almost certain	1
Person in open space if not buried by debris	Debris Flow	High chance of survival	0.1
Person in vehicle if partially buried by debris	Debris Flow	High chance of survival	0.1
Person in building if the building is inundated with debris and the person buried or building collapses	Debris Flow	Death is highly likely	1
If the debris strikes the building only	Debris Flow	High chance of survival	0.05

The values presented in the table above highlight the inherent vulnerability of persons in the event of complete or substantial burial by debris, such as would be the case should a Very Large or Extremely Large debris flow occur. In contrast, should an individual rockfall impact a conventional light vehicle, the chance of survival is relatively high. People in the open are obviously the most vulnerable and it should be noted that even small rockfalls can cause death.

## 16.5 Summary of Risk Estimation

Risks at the site have been estimated using in-house spreadsheets developed to address each of the elements at risk as summarised above. These calculations are presented in Appendix D.

We are not aware whether DIRDC has set Tolerable Risk Criteria for loss of life for Flying Fish Cove. In our experience many government departments and agencies choose to adopt the AGS (2007) suggested tolerable loss of life risk criteria for the person most at risk.

Table 12 presents a summary of the estimated annual risks of 'loss of life' to individuals most at risk that exceed the AGS (2007) suggested tolerable risk criteria for 'existing slopes'. The results highlight that the highest risks at the site are those associated with debris flows, not rockfalls. In addition, the elements at risk associated with these risks are all located in areas where berms are not present. It should be also be pointed out that many of the risks associated with rockfalls are still relatively high (in the order of  $10^{-5}$ ), however they would be considered tolerable according to the AGS (2007) suggested risk criteria.

**Table 12. Summary of Estimated Risks that Exceed AGS Suggested Tolerable Levels**

Area	Hazard	Elements at risk	Estimated Loss of Life Risk for the person most at risk ( per annum)
Boat Club Area / carpark	Very Large Debris Flow	Individuals in carpark (in open)	$1.39 \times 10^{-04}$
Boat Club Area / carpark	Extremely Large Debris Flow	Individuals in carpark (in open)	$1.58 \times 10^{-04}$
Marine Building	Very Large Debris Flow	Individuals working in Marine Building	$1.11 \times 10^{-03}$
Marine Building	Extremely Large Debris Flow	Individuals working in Marine Building	$6.31 \times 10^{-04}$
Madrasa / Shop Area	Very Large Debris Flow	Individuals in shop	$1.11 \times 10^{-04}$

# 17. Preliminary Assessment of Risk Mitigation Measures

## 17.1 Risk Mitigation Principles

The QRA indicates that elements at risk located close to the toe of the escarpment without berms present and with high occupancy, have high levels of risk. This should not be unexpected given the history of landsliding at the site. We understand that DIRDC are currently considering long term planning and redevelopment options for the Kampong. It is therefore an opportune time to investigate and subsequently integrate landslide mitigation measures into the long term plans for Flying Fish Cove. AGS (2007c) provides a useful summary of risk mitigation principles that should be considered and understood. An extract of the principles relevant to this project, together with our comments on each are provided below:

***“Accept the risk, which is only an option subject to the criteria set by the regulator. Where the risk is not tolerable then risk mitigation measures are required.”***

### Comments

This decision to pursue this option can only be made by DIRDC (The Regulator).

***“Avoid the risk, such as relocation of the site of proposed development, or revise the form of the development, or abandon the development.”***

### Comments

We envisage the abandonment of some buildings may be feasible should the Kampong be redeveloped. Buildings (i.e. Block 412A and Block 408) have previously been demolished due to high levels of landslide risk. However this may not be an option in cases such as the Marine Building due to the lack of suitable sites. Should DIRDC wish to further investigate this option further assessment of risks at potential sites and careful planning would need to be carried out.

***“Reduce the frequency of landsliding, by stabilisation measures to control the initiating circumstances, such as by re-profiling the surface geometry where existing slopes are ‘over steep’, by provision of improved surface water drainage measures, by provision of subsurface drainage scheme, by provision of retaining structures such as retaining walls, anchored walls or ground anchors.”***

### Comments

Due to the large extent of the site and environmental sensitivities (the site is a National Park), this option is impractical. Improvements to stormwater systems have recently been implemented at Drumsite and near the Territory Day Park to control stormwater discharges in these areas.

***“Reduce the consequences, by provision of defensive stabilisation measures or protective measures such as a rock fall fence, or amelioration of the behaviour of the landslide, or by relocation of the development to a more favourable location.”***

### Comments

The defensive measures that have been installed to date play a role in reducing the risks otherwise posed by landsliding. However, as the berms are only present in some locations and the rockfall barriers are unsuitable for controlling debris flow hazards, these hazards pose a high risk to a number of elements at risk. **The construction of new defensive measures comprising reinforced soil**

embankments would provide effective long term landslide risk mitigation for Flying Fish Cove. This option is further discussed below.

*“Manage the risk by establishing monitoring and warning systems, such as by regular site visits, or by survey, which enable the risks to be managed as an interim measure in the short term or as a permanent measure for the long term by alerting persons potentially affected to a change in the landslide condition. Such systems may be regarded as a method of reducing the consequences provided it is feasible for sufficient time to be available between the alert being raised and appropriate action being implemented.”*

#### Comments

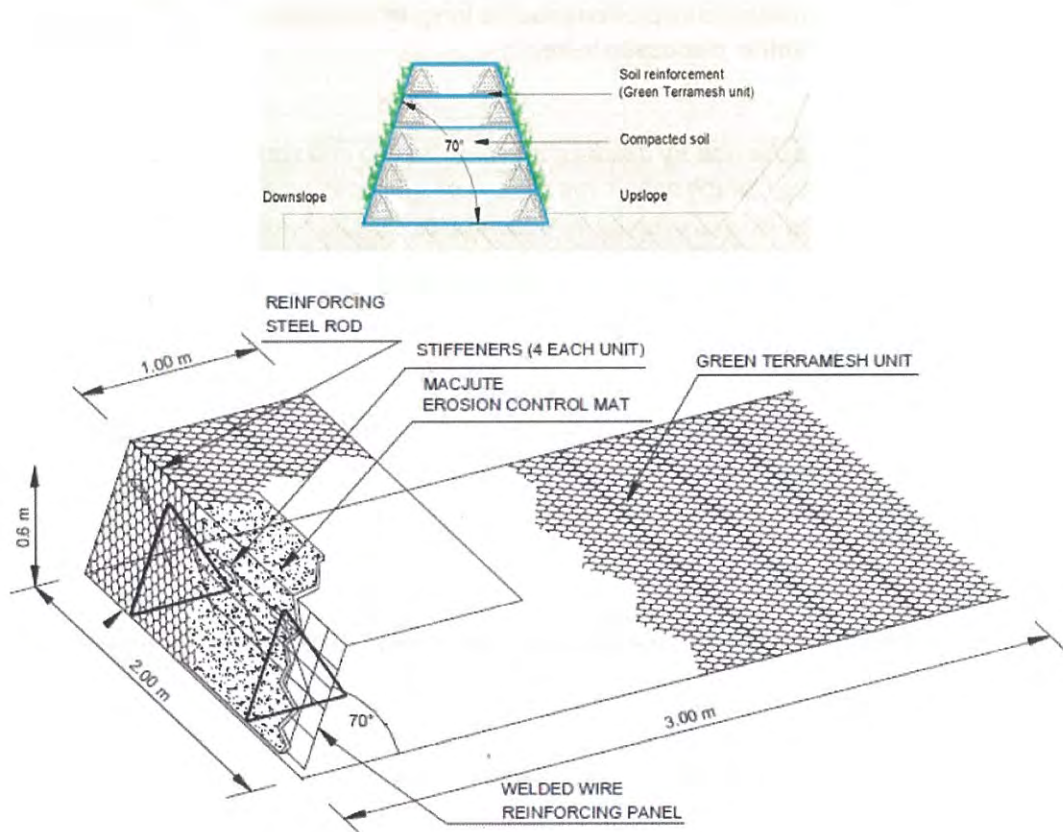
This principle is already being implemented in part via the RRMP and the annual inspection program. However, important as they are, these measures alone are not capable of reducing risks at the site to tolerable levels due to the rapid nature of the landslides.

## **17.2 Reinforced Soil Embankments**

We recommend DIRDC consider the construction of a series of reinforced soil embankments (i.e. berms) to provide long term protection from both debris flow and rockfall hazards. Reinforced soil structures incorporate reinforcing elements such as sheets, strips, nets or mats of metal, synthetic fabrics or fibre reinforced plastics arranged in the soil mass in such a way as to reduce or suppress the tensile strain which might develop under gravity and boundary forces. Such embankments could be constructed from locally sourced soils and or rock material. The main benefits of reinforced soil embankments for Flying Fish Cove are as follows:

- Theoretically unlimited energy absorption capacity.
- Resistance to multiple rockfall impacts.
- Negligible downslope deformation after the impact.
- Little to no maintenance required.
- High durability.
- Easy and rapid installation
- Could be constructed from locally sourced materials.

Maccaferri Pty Ltd design and supply proprietary rockfall / debris flow embankment systems such as the Green Terramesh® embankment that can be completely covered with vegetation to become a 'living structure'. A typical arrangement of a Green Terramesh® embankment is provided in Figure 15.



**Figure 15. Typical components and arrangement of a Green Terramesh® embankment (courtesy of Maccaferri Pty Ltd / Geofabrics)**



**Figure 16. Green Terramesh® embankments providing rockfall protection to road, Aosta Valley, Italy (Photo courtesy of Maccaferri Pty Ltd / Geofabrics).**

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**Figure 17. Green Terramesh® embankment providing debris flow protection to residential area, Christchurch, New Zealand. (Photo courtesy of Maccaferri Pty Ltd / Geofabrics)**

By constructing reinforced soil embankments upslope of areas currently not protected by berms (i.e. Boat Club, Marine Building and Madrasa areas), risks at the site would be reduced to tolerable or acceptable levels. These structures could readily be incorporated into future redevelopment and/or landscape plans for the Kampong. Even under the current Kampong layout there would be sufficient footprint construct these structures, however this may reduce the parking space in the Boat Club area.

We also recommend DIRDC consider replacing the existing berms with new embankments to provide a higher level of protection from rockfalls and increased debris catching capacity. This would create a continuous line of defences across the entire Kampong and render the existing rockfall barriers redundant. As a result the rockfall barriers would no longer need to be maintained or replaced.

Ideally, the embankments would need incorporate a level to gently sloping area upslope / behind the embankment to allow a backhoe or small excavator to periodically clean out accumulated debris. Apart from this periodic cleanout works (or possibly local repairs should a Large or Very Large rockfall cause damage) the structures would require virtually no maintenance.

Depending on the level of risk reduction DIRDC is seeking, the embankments could be designed to catch virtually any volume of debris or rockfall impact energy. This would obviously be subject to further modelling and assessment during the detailed design phase.

Depending on the size and position of the embankments if this scheme was to be adopted, the frequency of the annual geotechnical inspections could be reviewed with a view to reducing the frequency of inspections.

# 18. Discussion and Recommendations

## 18.1 Rockfall Risk Management Plan

We recommend the RRMP be reviewed and updated in light of the findings of this study. GHD are happy to provide specialist input and advice to assist DIRDC where required. A summary of some of the main issues identified in the RRMP are provided below:

- This study revealed that the highest risks at the site are those associated with debris flows, not rockfalls. However, debris flow hazards are not discussed in the RRMP. We recommend the hazards posed by landsliding be clearly defined in the RRMP based on the descriptions provided in this report.
- The flowchart on page 25 of the RRMP refers to rainfall thresholds that have been superseded.
- The plan on page 52 of the RRMP shows the location of a berm behind Block 403 that does not exist.
- The RRMP incorporates earthquake intensities to triggers both Level 1 and Level 2 warnings based on the Modified Mercalli (MM) Scale. Review and monitoring of earthquake magnitudes within a 500km of Christmas Island has been presented in the annual inspection reports and the five year review documents supplied, suggesting little correlation. Without correlating these events to intensity, in MM, felt in Flying Fish Cove, it is not appropriate to attempt to assess the appropriateness of the warning thresholds. In addition, given that rockfalls triggered by earthquakes are likely to occur within a very short time of the earthquake occurring (probably within seconds), it is almost inconceivable that individuals would have sufficient time to evacuate.
- The rainfall thresholds that trigger both Level 1 and Level 2 Conditions appear to be unusually precise (i.e. to the nearest 1 mm). We have not been provided with the report, if any, that these are based on. As discussed in Section 11, of particular interest is that of all the recorded Very Large and Extremely Large debris flows, not one occurred during a rainfall event exceeding the Level 2 threshold. This begs the obvious question: what is the Level 2 Condition aimed at predicting given that the rainfall thresholds exceed the 100 year AEP? In addition, all rockfalls, where rainfall data is available, occurred below the Level 1 thresholds. **Given these inconsistencies' we recommend the rainfall thresholds be reviewed and updated.**

## 18.2 UAV LiDAR Survey

As discussed in Section 3.2, the existing LiDAR survey while adequate for the purposes of the QRA, is limited in detail with some site features not accurately represented. The berms are not included in the survey at all. We recommend a high resolution UAV (Drone) LiDAR survey be carried out for the whole of Flying Fish Cove.

In the last few years rapid advances in UAV and LiDAR technology have seen the emergence of LiDAR sensors able to be fitted to UAV's and as a result these surveys have become relatively inexpensive. The survey point cloud densities now achievable by UAV LiDAR can exceed 400 points /m<sup>2</sup> with ground resolutions of < 50mm.

The acquisition of better quality survey data would allow some of the modelling to be refined (i.e. volume estimates) and would provide a detailed survey to be used for the basis of detailed design of the permanent risk mitigation works. The survey could also be used by DIRDC or other stakeholders for redevelopment or planning purposes.

### 18.3 Rockfall Research Program

Since the early 2000's, the rockfall research program and associated annual geotechnical inspections has provided valuable data on the history of landsliding in Flying Fish Cove. With almost 20 years of data gathered, it is an opportune time to reassess the focus of the annual inspections.

For sites such as the escarpment at Flying Fish Cove, it is judged impractical to conduct thorough visual assessments of specific slope hazards because the vast majority are either inaccessible or obscured by the dense vegetation. Therefore the observation and recording of features will inevitably be biased towards areas that are accessible. **Now that the nature of the landslide hazards are relatively well understood, we consider there is limited value to be gained from further annual traverses of the escarpment slopes.**

We recommend the annual inspections focus on the following tasks:

- Continue collecting data on rockfalls that reach the rockfall fence and updating the landslide inventory. Should a Medium or larger rockfall occur, we recommend an attempt be made at finding and describing the source conditions of the rockfall.
- Each annual report should include an updated landslide inventory. As discussed above, for the purposes of the QRA we removed data from the inventory relating to rockfalls and landslides that did not reach the vicinity of the rockfall fences. Should a Medium or larger rockfall be observed on the escarpment slopes that is obviously of recent origin, we recommend that these events be recorded in a separate inventory.
- While the existing rockfall barrier remains in service, the annual inspection should include a walkover of the fencelines and a general condition assessment of the barrier.
- When the occurrence / timing of debris flows and Medium or larger rockfalls is known, the rainfall conditions at the time should be reviewed and plotted on an IFD curve to be presented in the report. This should also be compared with the rainfall thresholds in the RRMP.
- Should a Very Large or Extremely Large debris flow occur, we recommend a geotechnical engineer or engineering geologist visit the site as soon as practicable to assess the damage caused, failure mechanisms and risks posed by further instability.
- More consideration should be given to the origin of rockfalls in the former railway cutting area. Most of the rockfalls in the inventory from this area appear to have originated from the railway cutting and not the natural slopes above. As a result, the data in this area is not particularly useful in further developing the QRA. For each rockfall, an assessment should be made on the likely source of the rockfall and this should be noted in the inventory.
- We also recommend that the escarpment slopes in the northern part of the site (i.e. above the Madrasa and Block 403) be observed where safe to do so. These slopes appear to have been given little attention to date. These observations are also important to verify the results of the rockfall modelling in this area that suggest rocks are unlikely to reach the toe of the escarpment. Where safe to do so, rockfall trials (controlled release of individual rocks from appropriate positions on the slope) could also be carried out.

## 18.4 Existing Rockfall Barrier

We recommend DIRDC consider the long term plans for Kampong and our recommendations for permanent landslide mitigation works before committing further funds and resources to maintaining the existing rockfall barriers. We expect that each time a Very Large or Extremely Large debris flow occurs, the rockfall barriers are likely to be knocked over or severely damaged. As discussed above, should reinforced soil embankments be constructed across the length of the site, the rockfalls barriers will no longer be required for rockfall protection.

Unfortunately, the manufacturer of the barriers no longer manufactures rockfall barriers or provides technical support to existing barriers. Owing to the fact that the reported design life of the structures has essentially expired, we understand DIRDC has commissioned a structural engineer to carry out periodic condition assessments of the barriers. These assessments, together with our observations generally found that the barriers are in apparent good conditions. Steel cables, shackles and wire rope clamps sometimes show signs of minor corrosion.

During our site visit to the Boat Club fence we observed disturbance of some of the shallow footings on which the posts are connected to. This was apparently caused by the 2017 debris flow. The damage that may have been caused to the ground anchors is not known.

At the time of our site visit, we discussed the condition of the fence with contractors that were reconstructing the barrier at the Boat Club area following its demolition by the 2017 debris flow. Based on the discussion it seems that the energy dissipaters on the barriers had not always functioned as intended.

Should DIRDC intend to rely on the rockfall barriers to provide some level of protection to the Kampong for say the next few years, we recommend a series of tests be carried out to help assess the current capacity of the barriers. We recommend the following:

- A series of pull-out and acceptance tests (i.e. load testing) on a selection of the ground anchors supporting the barrier. The condition of the anchors is currently not known and construction records are not available. We recommend that at least one pull out test be conducted on anchors likely to have been affected by the Boat Club landslides.
- Strength testing (to failure) of selected lengths of steel ropes taken from the barriers to assess whether the strength has reduced due to corrosion over time.
- Strength testing (to failure) of a selected energy dissipater devices to assess whether these are still operational. Depending on the outcome of the tests consideration should be given to replacing the old dissipaters with new dissipaters.

GHD would be happy to provide further details on the testing and oversee the works.

## 18.5 Berms

Unfortunately the design, construction methods and energy absorbing capacity of the berms are not known. In addition, as far as we are aware, the berms have never been impacted by a debris flow or rockfall, so their effectiveness in providing protection from hazards is uncertain. Should DIRDC intend to rely on the berms to provide some level of protection to the Kampong into the future, we recommend further geotechnical testing and analyses to assess the energy absorbing capacity of the berms. This would require a series of shallow test pits dug adjacent to the berms to assess the foundation conditions. We also recommend exposing a small section of the material within the berms to assess their composition. Following the testing we would carry out a series of numerical analyses to assess the capacity of the berms.

## 19. Closure

The QRA indicates that elements at risk located close to the toe of the escarpment without berms present and with high occupancy, have high levels of risk. In these areas, the estimated annual risks of 'loss of life' to individuals most at risk exceed the AGS (2007) suggested tolerable risk criteria for 'existing slopes'.

We recommend that decisions about acceptable and/or tolerable risk and risk management be based on the AGS (2007) Landslide Risk Management Guidelines, according to standard industry practice. The level of acceptable or tolerable risk for both loss of life and property, depends on many factors. GHD can work with you or your stakeholders to help you decide on a level of risk that is acceptable or tolerable.

AGS (2007) states that in many cases, the ALARP principle ("As Low As Reasonably Practicable") may apply so that reduction to a tolerable level is a pragmatic result since reduction to acceptable levels is not viable in the context of the cost to the individual or community. In essence this principle states that risk reduction measures should be carried out until it can be demonstrated that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained.

The risk mitigation options discussed above relating to reinforced soil embankments will require geotechnical investigations and analyses to allow detailed design to proceed. GHD can work with you to develop and deliver these options throughout the full life cycle of the project.

This report outlines our observations of geotechnical site features and assessment of landslide and rock fall hazards observable at the time of the fieldwork. Natural features will change and may deteriorate over time, which could change existing hazards or create new ones. Additional investigations may be required to further assess landslide hazards, risk mitigation measures, ongoing monitoring and maintenance requirements.

## 20. References

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- Varnes, D J (1978) Slope Movement Types and Processes. In Special Report 176: Landslides: Analysis and Control (R L Schuster & R J Krizek, eds.), TRB, National Research Council, Washington, DC, pp.11-33).

# Appendices

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## Appendix A – ‘A Series’ Figures

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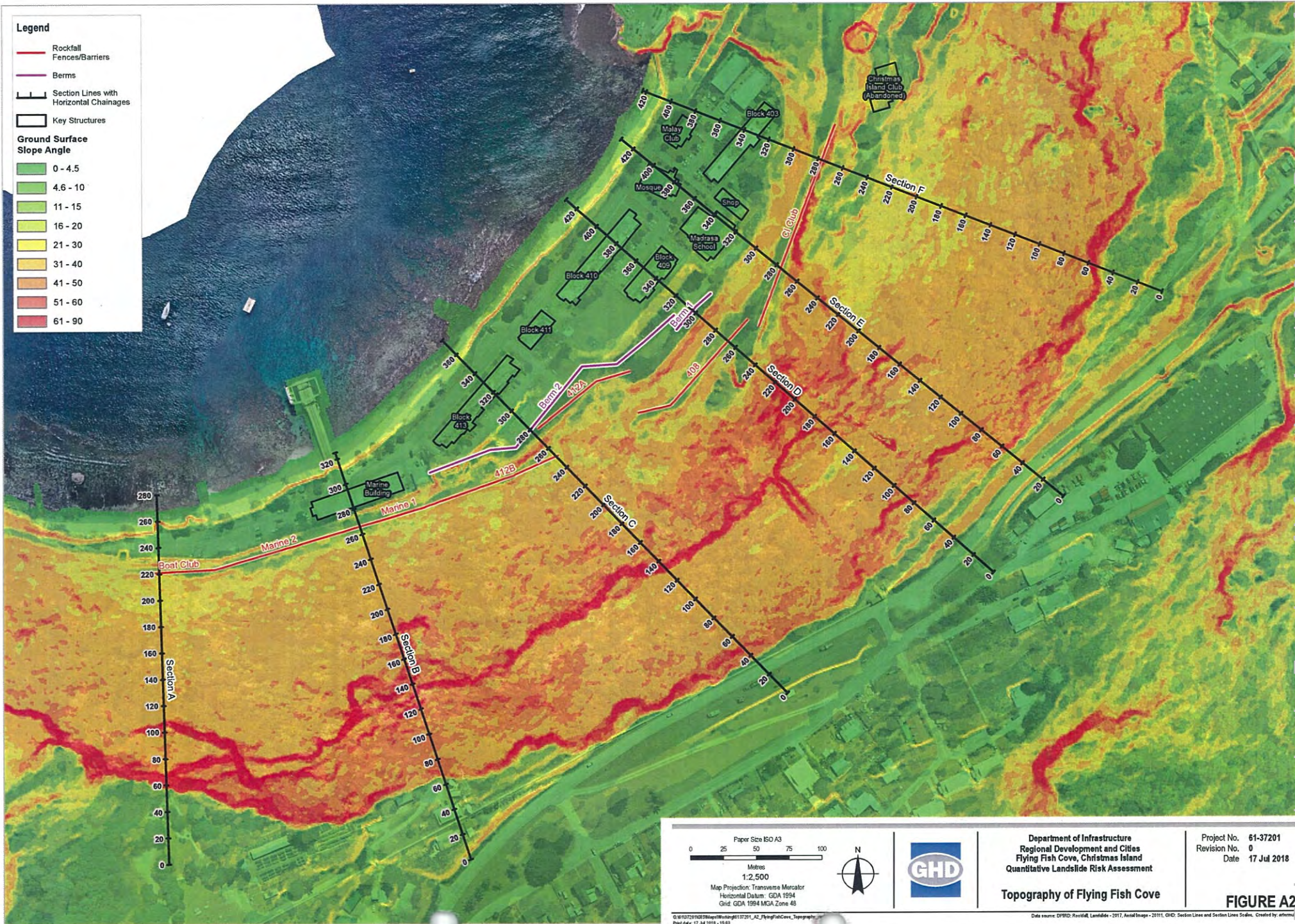
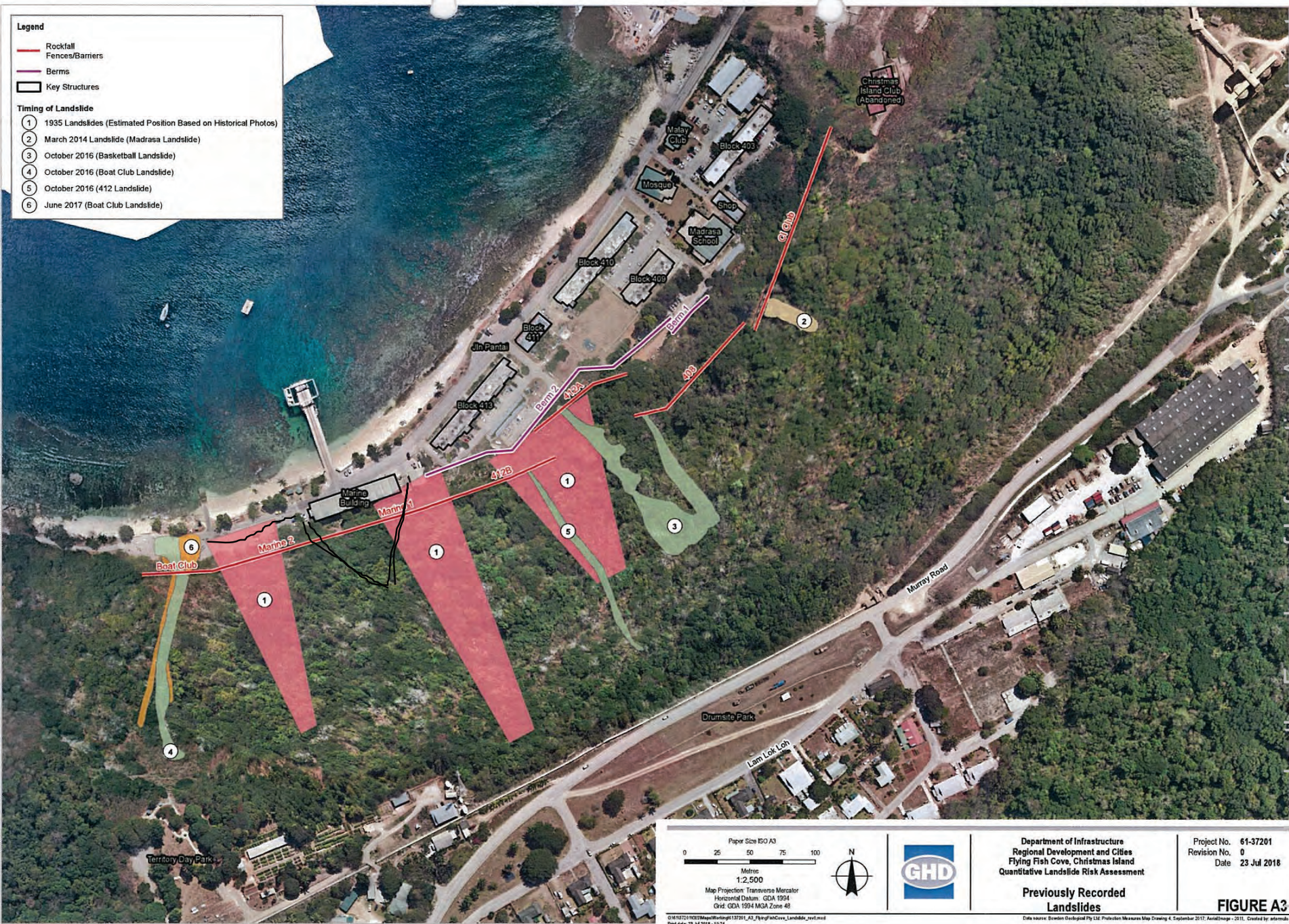


FIGURE A2

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**Legend**

- Rockfall
- Fences/Barriers
- Berms
- Key Structures

**Timing of Landslide**

- ① 1935 Landslides (Estimated Position Based on Historical Photos)
- ② March 2014 Landslide (Madrasa Landslide)
- ③ October 2016 (Basketball Landslide)
- ④ October 2016 (Boat Club Landslide)
- ⑤ October 2016 (412 Landslide)
- ⑥ June 2017 (Boat Club Landslide)

Paper Size EGO A3

0 25 50 75 100

Metres

1:2,500

Map Projection Transverse Mercator  
Horizontal Datum: GDA 1994  
Grid: GDA 1994 MGA Zone 48



Department of Infrastructure  
Regional Development and Cities  
Flying Fish Cove, Christmas Island  
Quantitative Landslide Risk Assessment

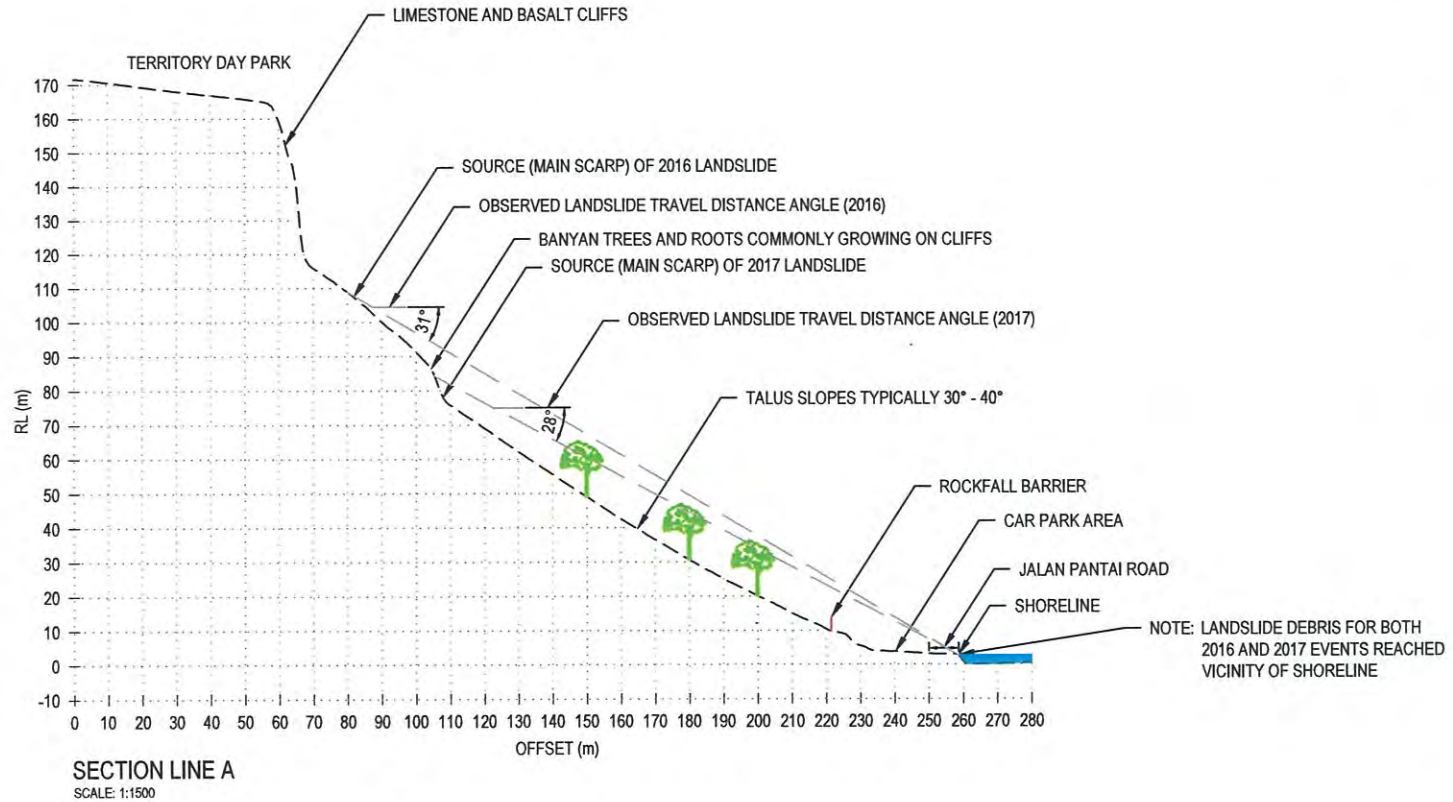
**Previously Recorded Landslides**

Project No. 61-37201  
Revision No. 0  
Date 23 Jul 2018

**FIGURE A3**

Q:\10751\10219\Map\Working\137201\_A3\_FlyFishCove\_Landslide\_rpt.mxd  
Date: 23 Jul 2018 - 10:24  
Data source: Swinerton Geospatial Pty Ltd, Precision Measures Map Drawing 4, September 2017, AerialImage - 2011, Created by: alexmaki

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**GENERAL NOTES:**

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. ALL LEVEL ARE RELATED TO AUSTRALIAN HEIGHT DATUM (AHD).
3. SLOPE PROFILE IS BASED ON LIDAR SURVEY MAPPING PROVIDED BY CLIENT (FILE REFERENCE: "RASTER1m.dwg").

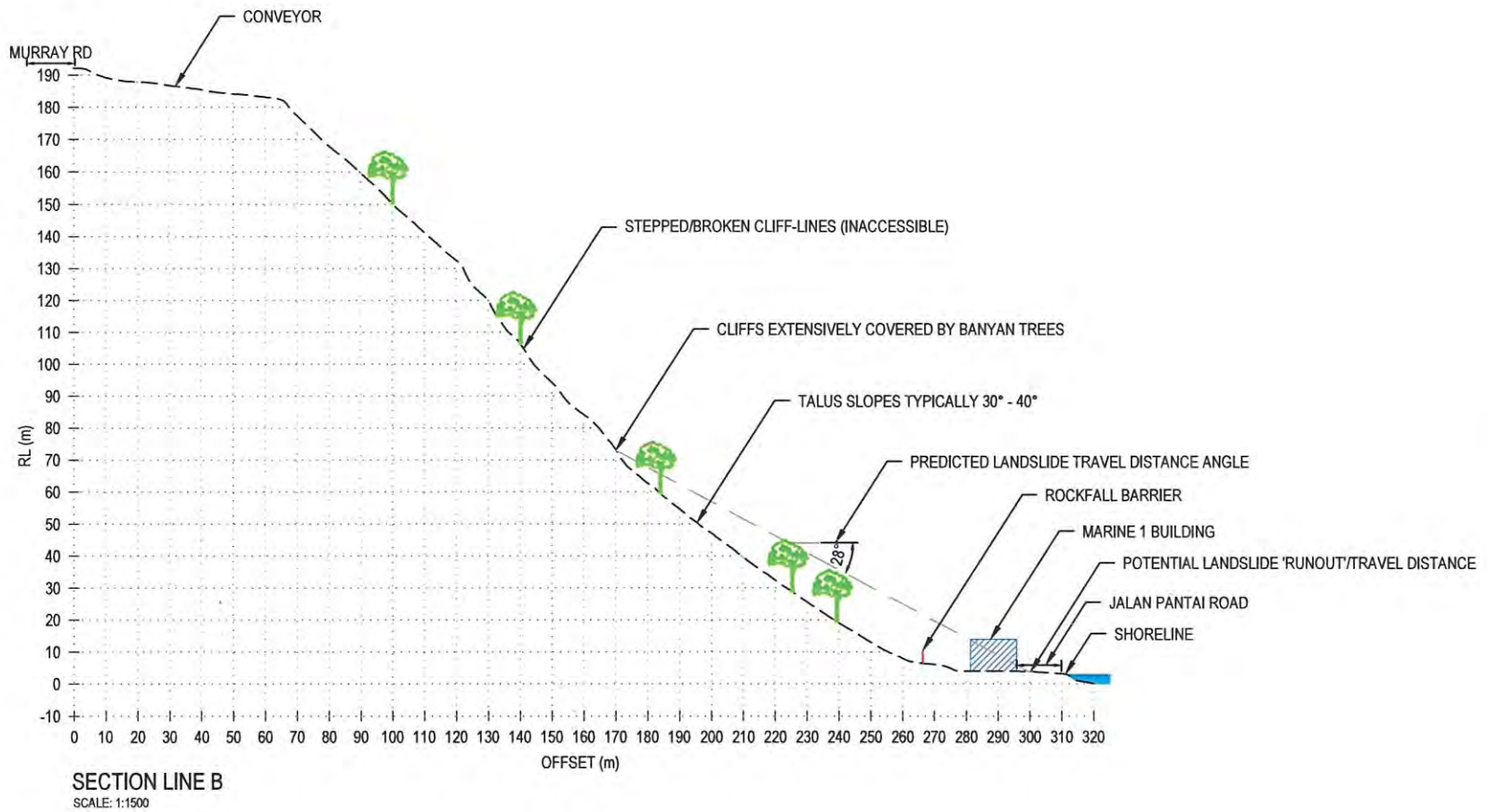


DEPARTMENT OF INFRASTRUCTURE & REGIONAL DEVELOPMENT Job Number 61-37201  
 FLYING FISH COVE, CHRISTMAS ISLAND Revision A  
 QUANTITATIVE LANDSLIDE RISK ASSESSMENT Date JULY 2018

**SECTION A**

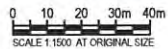
**Figure A4**

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2. ALL LEVEL ARE RELATED TO AUSTRALIAN HEIGHT DATUM (AHD).
3. SLOPE PROFILE IS BASED ON LIDAR SURVEY MAPPING PROVIDED BY CLIENT (FILE REFERENCE: "RASTER1m.adf").

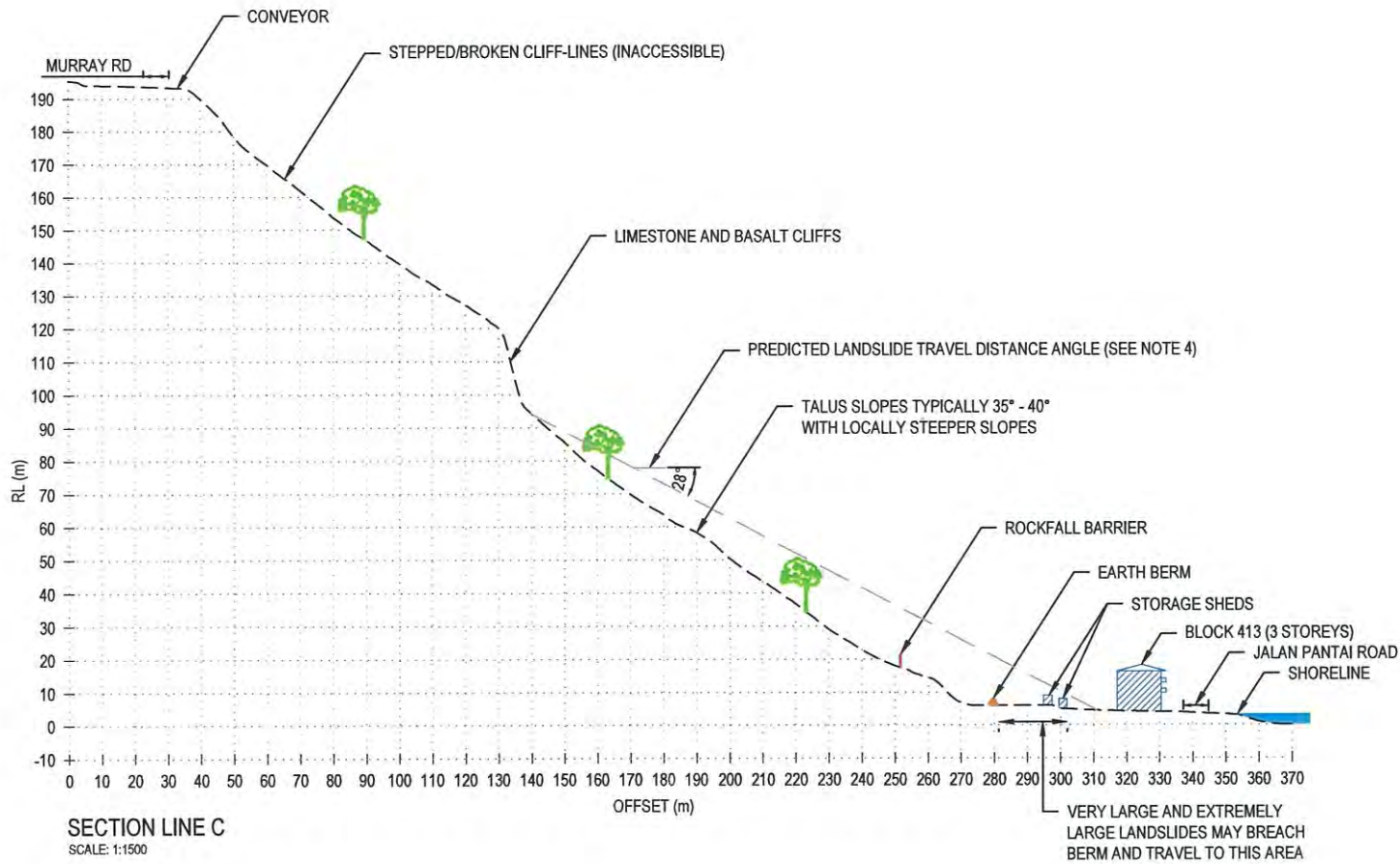


DEPARTMENT OF INFRASTRUCTURE & REGIONAL DEVELOPMENT Job Number 61-37201  
 FLYING FISH COVE, CHRISTMAS ISLAND Revision A  
 QUANTITATIVE LANDSLIDE RISK ASSESSMENT Date JULY 2018

**SECTION B**

**Figure A5**

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1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. ALL LEVEL ARE RELATED TO AUSTRALIAN HEIGHT DATUM (AHD).
3. SLOPE PROFILE IS BASED ON LIDAR SURVEY MAPPING PROVIDED BY CLIENT (FILE REFERENCE: "RASTER1m.adr").
4. THE PREDICTED TRAVEL DISTANCE DOES NOT CONSIDER PROTECTION PROVIDED BY BERM. BERM CAPACITY IS APPROXIMATELY 700m<sup>2</sup> - 1000m<sup>2</sup> PER 20m LENGTH OF BERM.

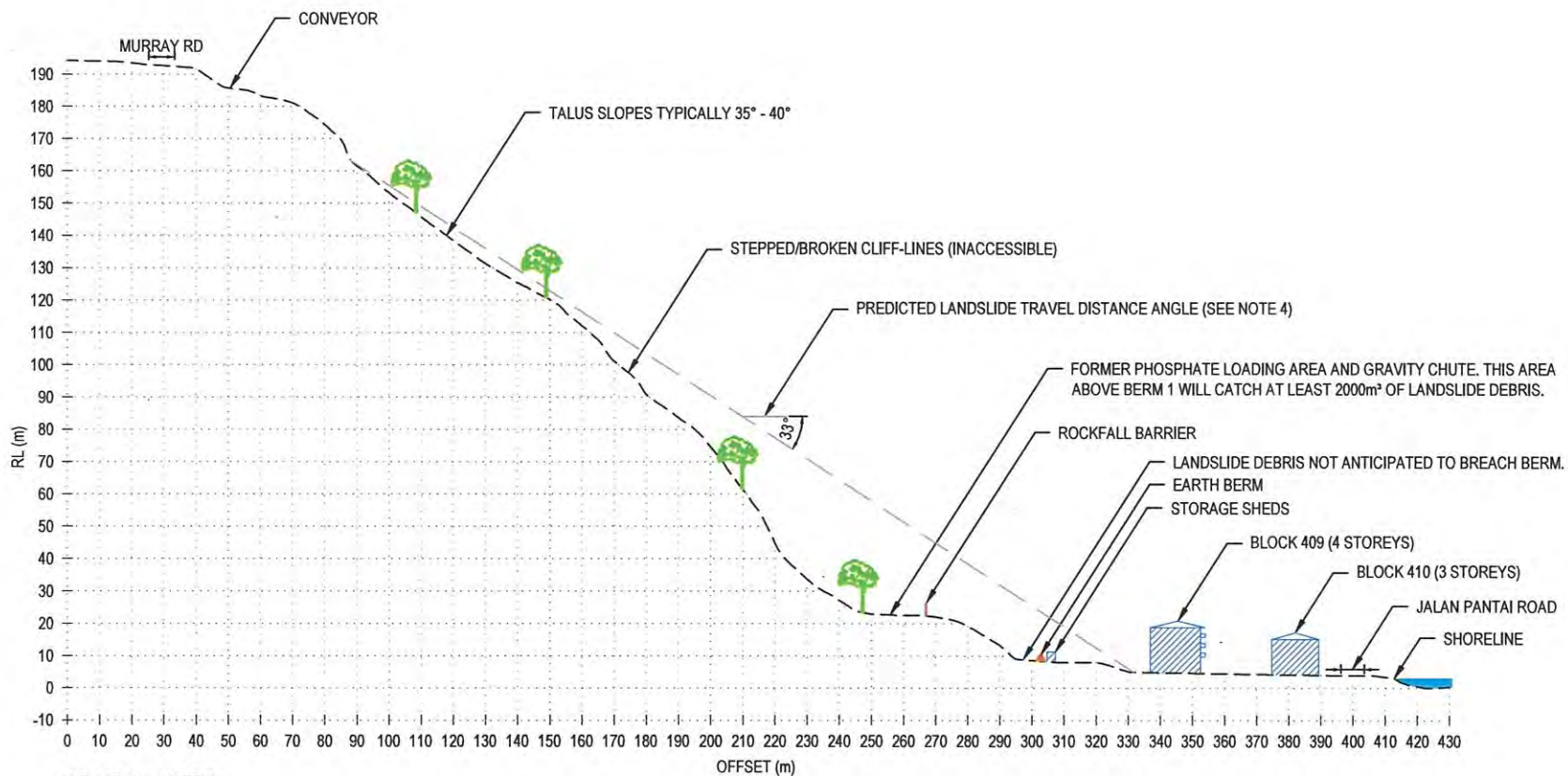


DEPARTMENT OF INFRASTRUCTURE & REGIONAL DEVELOPMENT Job Number | 61-37201  
 FLYING FISH COVE, CHRISTMAS ISLAND Revision | A  
 QUANTITATIVE LANDSLIDE RISK ASSESSMENT Date | JULY 2018

**SECTION C**

**Figure A6**

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SECTION LINE D  
SCALE: 1:1500

**GENERAL NOTES:**

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2. ALL LEVEL ARE RELATED TO AUSTRALIAN HEIGHT DATUM (AHD).
3. SLOPE PROFILE IS BASED ON LIDAR SURVEY MAPPING PROVIDED BY CLIENT (FILE REFERENCE: "RASTER1m.adf").
4. THE PREDICTED TRAVEL DISTANCE DOES NOT CONSIDER PROTECTION PROVIDED BY BERM OR BENCHING AREA AT PHOSPHATE LOADING AREA. BERM 1 CAPACITY IS APPROXIMATELY 800m².

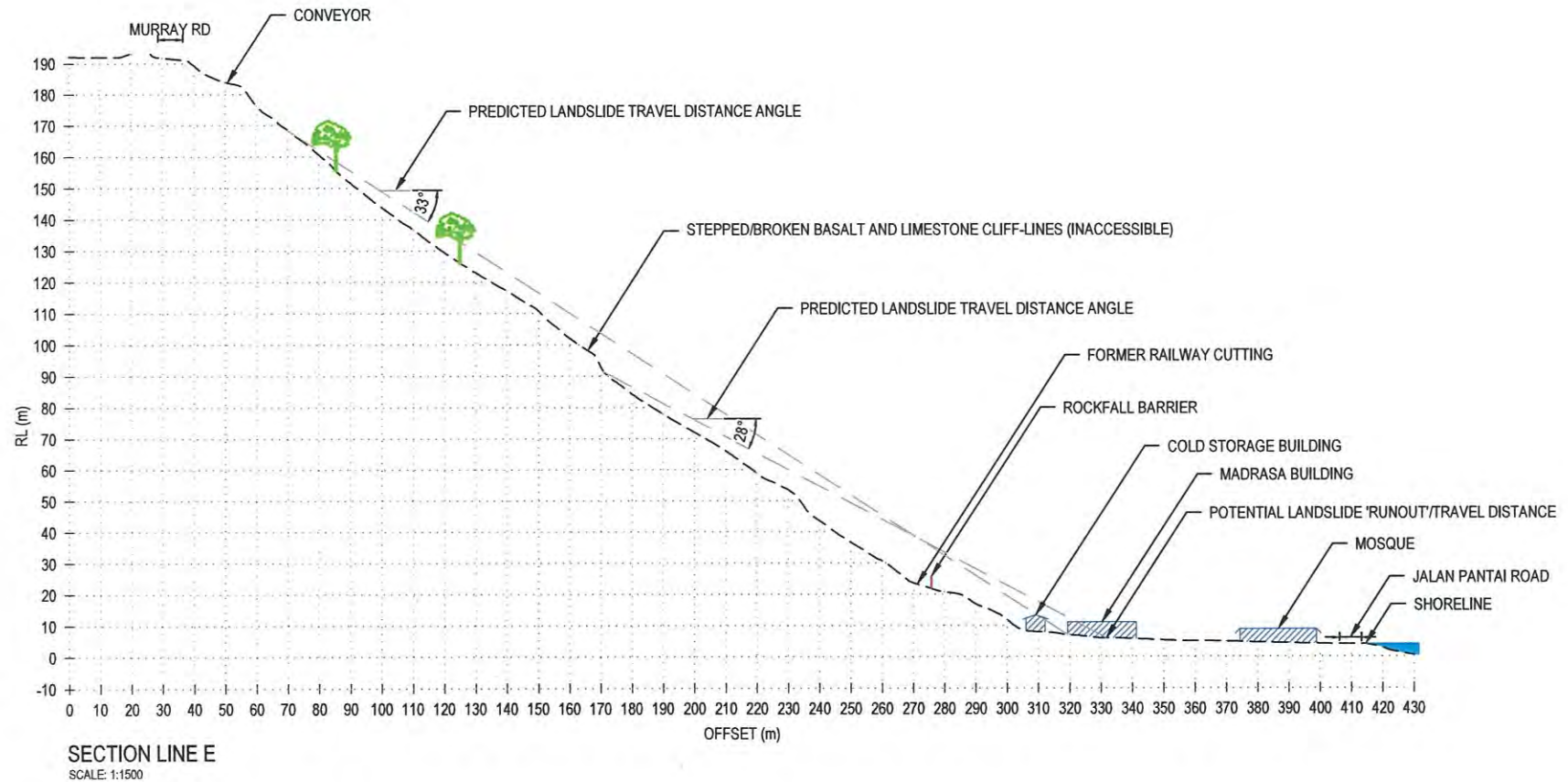


DEPARTMENT OF INFRASTRUCTURE & REGIONAL DEVELOPMENT Job Number | 61-37201  
 FLYING FISH COVE, CHRISTMAS ISLAND Revision | A  
 QUANTITATIVE LANDSLIDE RISK ASSESSMENT Date | JULY 2018

SECTION D

Figure A7

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**GENERAL NOTES:**

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3. SLOPE PROFILE IS BASED ON LIDAR SURVEY MAPPING PROVIDED BY CLIENT (FILE REFERENCE: "RASTER1m.adf").

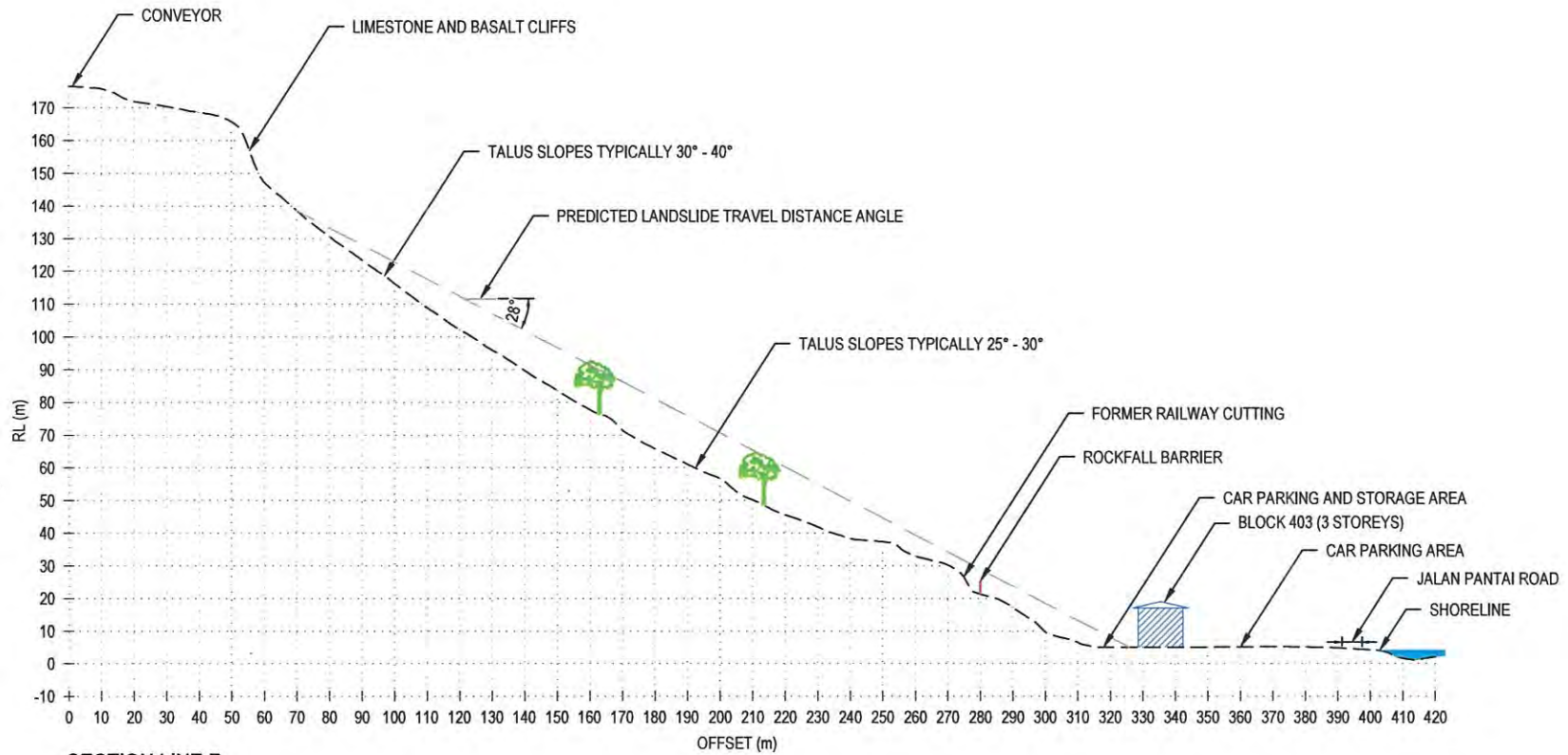


DEPARTMENT OF INFRASTRUCTURE & REGIONAL DEVELOPMENT Job Number | 61-37201  
 FLYING FISH COVE, CHRISTMAS ISLAND Revision | A  
 QUANTITATIVE LANDSLIDE RISK ASSESSMENT Date | JULY 2018

**SECTION E**

**Figure A8**

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SECTION LINE F  
SCALE: 1:1500

**GENERAL NOTES:**

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
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 FLYING FISH COVE, CHRISTMAS ISLAND Revision A  
 QUANTITATIVE LANDSLIDE RISK ASSESSMENT Date JULY 2018

SECTION F

Figure A9

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## Appendix B – Landslide Inventory

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**Table B1. Landslide Inventory**

Event	Year	Observation Date	Landslide type	Event Volume	Event Landslide Category	Location (Protection Fence)	Distance from fence (m)		Comments
1	1895	1/1/1895	Rock	3.923	Medium	412B/412A	0-18	m from fence	anecdotal
2	1930	1/01/1930	Rock	2.071	Medium	408B/CI Club	-40	m past fence	
3	1935	18/04/1935	Debris & Rock	1889	Extremely large	412A, 412B, 408, Marine 1	-10 to -45	m past fence	Positions assessed from historic photos and map in Golder (1995)
4	1972	20 and 21/03/1972	rock	144	Very Large	Boat Club	0 to -33	m past fence	
5	1974	1/01/1974	Rock	1.4	Medium	Boat Club	0	at fence	
6	1975	1/01/1975	Rock	22	Large	Marine 1	0	at fence	
7	1983	1/01/1983	rock	2.5	Medium	Boat Club	-10	m past fence	
8	1985	1/01/1985	rock			412B/408	0 to -50	m past fence	
9	1992	1/02/1992	Rock	2.75	Medium	Boat Club	-15	m past fence	
10	1995	1/02/1995	Rock	12	Large	CI Club	-10	m past fence	
11	1999	1/04/1999	Rock	4	Medium	Boat Club	0	at fence	
12	2001	30/08/2001	Rock	0.111	Small	CI Club	1.3	m from fence	From monthly inspection, no exact date
13	2001	30/10/2001	rock	0.033	Very small	CI club	3.1	m from fence	From monthly inspection, no exact date
14	2001	30/10/2001	rock	0.075	Very small	408B	2.7	m from fence	From monthly inspection, no exact date
15	2001	30/10/2001	rock	0.053	Very small	412B	2	m from fence	From monthly inspection, no exact date
16	2001	30/10/2001	rock	0.029	Very small	412B	2.5	m from fence	From monthly inspection, no exact date
17	2001	30/10/2001	rock	0.035	Very small	412B	2.5	m from fence	From monthly inspection, no exact date
18	2001	30/10/2001	rock	0.026	Very small	412B	0	at fence	From monthly inspection, no exact date
19	2001	30/10/2001	rock	0.020	Very small	Marine 1	2.2	m from fence	From monthly inspection, no exact date

B1

This page must be read in conjunction with the following report:  
 Flying Fish Cove, Christmas Island - Quantitative Landslide Risk Assessment. Report Ref: 6137201-5937. July 2018



Event	Year	Observation Date	Landslide type	Event Volume	Event Landslide Category	Location (Protection Fence)	Distance from fence (m)		Comments
20	2001	30/10/2001	rock	0.089	Very small	Marine 1	3.1	m from fence	From monthly inspection, no exact date
21	2001	30/10/2001	rock	0.012	Very small	Marine 2	2.6	m from fence	From monthly inspection, no exact date
22	2001	20/11/2001	rock	0.016	Very small	408B	3.2	m from fence	From monthly inspection, no exact date
23	2001	20/11/2001	rock	0.296	Small	Marine 1	4.3	m from fence	From monthly inspection, no exact date
24	2001	20/11/2001	rock	0.027	Very small	Marine 1	3.7	m from fence	From monthly inspection, no exact date
25	2001	20/11/2001	rock	0.045	Very small	Marine 1	4.5	m from fence	From monthly inspection, no exact date
26	2001	19/12/2001	Rock	0.008	Extremely small	412A	0.04	at fence	From monthly inspection, no exact date
27	2002	22/02/2002	Debris	3.351	Medium	Cl club	1.5	m from fence	From monthly inspection, no exact date
28	2002	22/02/2002	Rock	0.064	Very small	Marine 2	0.3	m from fence	From monthly inspection, no exact date
29	2002	22/02/2002	Rock	0.100	Small	Marine 1	0.7	m from fence	From monthly inspection, no exact date
30	2002	22/02/2002	Rock	0.014	Very small	412B	0.3	m from fence	From monthly inspection, no exact date
31	2002	22/02/2002	Rock	0.015	Very small	412B	1.1	m from fence	From monthly inspection, no exact date
32	2002	22/02/2002	Rock	0.140	Small	412B	0	at fence	From monthly inspection, no exact date
33	2002	22/02/2002	Rock	0.027	Very small	412B	0.2	m from fence	From monthly inspection, no exact date
34	2002	22/02/2002	Rock	0.120	Small	412B	0.3	m from fence	From monthly inspection, no exact date
35	2002	22/02/2002	Rock	0.024	Very small	412B	0.3	m from fence	From monthly inspection, no exact date
36	2002	22/02/2002	Rock	0.160	Small	412B	1.5	m from fence	From monthly inspection, no exact date
37	2002	22/02/2002	Rock	0.011	Very small	412B	1.6	m from fence	From monthly inspection, no exact date

B2



Event	Year	Observation Date	Landslide type	Event Volume	Event Landslide Category	Location (Protection Fence)	Distance from fence (m)		Comments
38	2002	22/02/2002	Rock	0.018	Very small	412A	1.6	m from fence	From monthly inspection, no exact date
39	2002	8/04/2002	rock	0.041	Very small	Marine 1	1.8	m from fence	From monthly inspection, no exact date
40	2002	26/06/2002	rock	0.030	Very small	Cl club	1.5	m from fence	From monthly inspection, no exact date
41	2002	26/06/2002	rock	0.020	Very small	Cl club	3.2	m from fence	From monthly inspection, no exact date
42	2002	26/06/2002	rock	0.021	Very small	408B	3.5	m from fence	From monthly inspection, no exact date
43	2002	26/06/2002	rock	0.025	Very small	Marine 2	2.5	m from fence	From monthly inspection, no exact date
44	2002	26/06/2002	rock	0.016	Very small	Marine 1	0.03	m from fence	From monthly inspection, no exact date
45	2002	26/06/2002	rock	0.030	Very small	Marine 1	2.3	m from fence	From monthly inspection, no exact date
46	2002	26/06/2002	rock	0.010	Very small	412B	0.04	m from fence	From monthly inspection, no exact date
47	2002	4/09/2002	rock	0.036	Very small	Boat Club	2.3	m from fence	From monthly inspection, no exact date
48	2002	4/09/2002	rock	0.015	Very small	Marine 1	1.6	m from fence	From monthly inspection, no exact date
49	2002	16/10/2002	Rock	0.021	Very small	408B	2.5	m from fence	From monthly inspection, no exact date
50	2002	16/10/2002	Rock	0.018	Very small	Boat Club	2.2	m from fence	From monthly inspection, no exact date
51	2002	16/10/2002	Rock	0.018	Very small	Marine 1	2.8	m from fence	From monthly inspection, no exact date
52	2002	16/10/2002	Rock	0.013	Very small	Marine 1	2.9	m from fence	From monthly inspection, no exact date
53	2002	16/10/2002	Rock	0.008	Extremely small	Marine 1	2.9	m from fence	From monthly inspection, no exact date



Event	Year	Observation Date	Landslide type	Event Volume	Event Landslide Category	Location (Protection Fence)	Distance from fence (m)		Comments
54	2002	16/10/2002	Rock	0.015	Very small	Marine 1	2.1	m from fence	From monthly inspection, no exact date
55	2002	16/10/2002	Rock	0.012	Very small	Marine 1	2	m from fence	From monthly inspection, no exact date
56	2002	16/10/2002	Rock	0.096	Very small	Marine 1	3.1	m from fence	From monthly inspection, no exact date
57	2002	16/10/2002	Rock	0.016	Very small	412B	0.45	m from fence	From monthly inspection, no exact date
58	2002	16/10/2002	Rock	0.026	Very small	412B	2.6	m from fence	From monthly inspection, no exact date
59	2002	16/10/2002	Rock	0.004	Extremely small	412A	1.9	m from fence	From monthly inspection, no exact date
60	2002	10/12/2002	rock	0.026	Very small	Marine 1	2.2	m from fence	From monthly inspection, no exact date
61	2002	10/12/2002	rock	0.010	Very small	Marine 1	1	m from fence	From monthly inspection, no exact date
62	2003	8/01/2003	Rock	0.009	Very small	CI Club	0.04	at fence	From monthly inspection, no exact date
63	2003	8/01/2003	Rock	0.060	Very small	Marine 2	0.07	at fence	From monthly inspection, no exact date
64	2003	8/01/2003	Rock	0.012	Very small	Marine 2	0	at fence	From monthly inspection, no exact date
65	2003	8/01/2003	Rock	0.126	Small	412B	0	at fence	From monthly inspection, no exact date
66	2003	26/03/2003	Rock	0.045	Very small	Marine 2	0	at fence	From monthly inspection, no exact date
67	2003	14/05/2003	Rock	0.324	Small	Marine 1	3.1	m from fence	From monthly inspection, no exact date
68	2003	14/05/2003	Rock	0.041	Very small	Marine 1	3.7	m from fence	From monthly inspection, no exact date
69	2003	14/05/2003	Rock	0.006	Extremely small	Marine 1	3.1	m from fence	From monthly inspection, no exact date
70	2003	14/05/2003	Rock	0.008	Extremely small	412B	0.05	at fence	From monthly inspection, no exact date

B4



Event	Year	Observation Date	Landslide type	Event Volume	Event Landslide Category	Location (Protection Fence)	Distance from fence (m)		Comments
71	2003	14/05/2003	Rock	0.014	Very small	412B	1	m from fence	From monthly inspection, no exact date
72	2003	14/05/2003	Rock	0.034	Very small	412B	1	m from fence	From monthly inspection, no exact date
73	2003	7/07/2003	Rock	0.016	Very small	Boat Club	4.5	m from fence	From monthly inspection, no exact date
74	2003	29/09/2003	rock	0.011	Very small	Marine 2	2.4	m from fence	From monthly inspection, no exact date
75	2003	29/09/2003	rock	0.018	Very small	412A	0	at fence	From monthly inspection, no exact date
76	2003	11/02/2003	rock	0.583	Small	Marine 2, 412A/B	2.9 to 0.03	m from fence	
77	2003	28/11/2003	Rock	0.072	Very small	CI Club	3.9	m from fence	From monthly inspection, no exact date
78	2003	28/11/2003	Rock	0.024	Very small	CI Club	0.12	m from fence	From monthly inspection, no exact date
79	2003	28/11/2003	Rock	0.009	Extremely small	CI Club	2.58	m from fence	From monthly inspection, no exact date
80	2003	28/11/2003	Rock	0.011	Very small	408B	2.23	m from fence	From monthly inspection, no exact date
81	2003	28/11/2003	Rock	0.023	Very small	412B	0.49	m from fence	From monthly inspection, no exact date
82	2003	28/11/2003	Rock	0.039	Very small	412B	0.57	m from fence	From monthly inspection, no exact date
83	2003	28/11/2003	Rock	0.023	Very small	412B	0.2	m from fence	From monthly inspection, no exact date
84	2004	7/04/2004	Rock	0.054	Very small	408B	1.76	m from fence	From monthly inspection, no exact date
85	2004	7/04/2004	Rock	0.031	Very small	Boat Club	0	at fence	From monthly inspection, no exact date
86	2004	7/04/2004	Rock	0.070	Very small	Marine 2	0.67	m from fence	From monthly inspection, no exact date
87	2004	7/04/2004	Rock	0.340	Small	Marine 2	2.71	m from fence	From monthly inspection, no exact date

B5

This page must be read in conjunction with the following report:

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Event	Year	Observation Date	Landslide type	Event Volume	Event Landslide Category	Location (Protection Fence)	Distance from fence (m)		Comments
88	2004	7/04/2004	Rock	0.056	Very small	Marine 2	0.35	m from fence	From monthly inspection, no exact date
89	2004	7/04/2004	Rock	0.042	Very small	Marine 1	1.44	m from fence	From monthly inspection, no exact date
90	2004	7/04/2004	Rock	0.080	Very small	412B	2.05	m from fence	From monthly inspection, no exact date
91	2004	7/04/2004	Rock	0.037	Very small	412B	0.55	m from fence	From monthly inspection, no exact date
92	2004	4/06/2004	Rock	0.016	Very small	Marine 1	0.21	m from fence	From monthly inspection, no exact date
93	2004	4/06/2004	Rock	0.034	Very small	Marine 2	1	m from fence	From monthly inspection, no exact date
94	2004	4/06/2004	Rock	0.367	Small	Marine 2	2.9	m from fence	From monthly inspection, no exact date
95	2004	4/06/2004	Rock	0.017	Very small	Marine 2	1.26	m from fence	From monthly inspection, no exact date
96	2004	12/07/2004	rock	0.033	Very small	408B	0	at fence	From monthly inspection, no exact date
97	2004	12/07/2004	rock	0.022	Very small	Marine 2	2.3	m from fence	From monthly inspection, no exact date
98	2005	13/01/2005	rock	0.064	Very small	Boat Club	0	at fence	From monthly inspection, no exact date
99	2005	13/01/2005	rock	0.014	Very small	Boat Club	0.53	m from fence	From monthly inspection, no exact date
100	2005	7/03/2005	rock	0.205	Small	Boat Club	0	at fence	From monthly inspection, no exact date
101	2005	7/03/2005	rock	0.015	Very small	Marine 2	0	at fence	From monthly inspection, no exact date
102	2005	7/03/2005	rock	0.089	Very small	Marine 2	2.76	m from fence	From monthly inspection, no exact date
103	2005	7/03/2005	rock	0.021	Very small	Marine 2	0.13	m from fence	From monthly inspection, no exact date
104	2006	3/02/2006	rock	0.072	Very small	412B	0	at fence	From monthly inspection, no exact date

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Event	Year	Observation Date	Landslide type	Event Volume	Event Landslide Category	Location (Protection Fence)	Distance from fence (m)		Comments
105	2006	3/02/2006	rock	0.011	Very small	Boat Club	0	at fence	From monthly inspection, no exact date
106	2007	24/10/2007	rock	1.000	Small	408B	0	at fence	From monthly inspection, no exact date
107	2008	13/02/2008	rock	0.125	Small	408B	0	at fence	From monthly inspection, no exact date
108	2008	7/05/2008	rock	0.060	Very small	412B	0	at fence	From monthly inspection, no exact date
109	2010	22/12/2010	rock	0.400	Small	408B	0	at fence	From monthly inspection, no exact date
110	2010	22/12/2010	rock	0.075	Very small	412B	2	m from fence	From monthly inspection, no exact date
111	2010	22/12/2010	rock	0.128	Small	412B	4	m from fence	From monthly inspection, no exact date
112	2010	22/12/2010	rock	0.280	Small	412B	0	at fence	From monthly inspection, no exact date
113	2010	22/12/2010	rock	0.009	Extremely small	412B	2	m from fence	From monthly inspection, no exact date
114	2010	22/12/2010	rock	0.055	Very small	Marine 1	0	at fence	From monthly inspection, no exact date
115	2010	22/12/2010	rock	0.016	Very small	Marine 1	0	at fence	From monthly inspection, no exact date
116	2010	22/12/2010	rock	0.016	Very small	Marine 1	0	at fence	From monthly inspection, no exact date
117	2010	22/12/2010	rock	0.096	Very small	Marine 1	1	m from fence	From monthly inspection, no exact date
118	2010	22/12/2010	rock	0.072	Very small	Marine 1	2.5	m from fence	From monthly inspection, no exact date
119	2010	22/12/2010	rock	0.280	Small	Marine 1	0	at fence	From monthly inspection, no exact date
120	2010	22/12/2010	rock	0.027	Very small	Marine 1	0	at fence	From monthly inspection, no exact date
121	2010	22/12/2010	rock	0.016	Small	Marine 2	0	at fence	From monthly inspection, no exact date
122	2010	22/12/2010	rock	0.008	Extremely small	Marine 2	0	at fence	From monthly inspection, no exact date
123	2010	22/12/2010	rock	0.016	Very small	Boat Club	0	at fence	From monthly inspection, no exact date

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This page must be read in conjunction with the following report:

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Event	Year	Observation Date	Landslide type	Event Volume	Event Landslide Category	Location (Protection Fence)	Distance from fence (m)		Comments
124	2010	22/12/2010	rock	0.016	Very small	Boat Club	0	at fence	From monthly inspection, no exact date
125	2011	14/02/2011	rock	0.512	Small	Boat Club	0	at fence	From monthly inspection, no exact date
126	2011	18/11/2011	rock	0.240	Small	Marine 1	0	at fence	From monthly inspection, no exact date
127	2011	18/11/2011	rock	0.064	Very small	Marine 1	1	m from fence	From monthly inspection, no exact date
128	2011	18/11/2011	rock	0.012	Very small	Marine 1	1	m from fence	From monthly inspection, no exact date
129	2012	17/05/2012	rock	0.252	Small	408	0	at fence	From monthly inspection, no exact date
130	2012	17/05/2012	rock	0.216	Small	408	3	m from fence	From monthly inspection, no exact date
131	2012	17/05/2012	rock	0.144	Small	408	3	m from fence	From monthly inspection, no exact date
132	2012	17/05/2012	rock	0.200	Small	408	3	m from fence	From monthly inspection, no exact date
133	2012	17/05/2012	rock	0.027	Very small	Marine 2	0	Cluster of small rocks	From monthly inspection, no exact date
134	2013	29/10/2013	rock	0.729	Small	Marine 1	0	at fence	From monthly inspection, no exact date
135	2013	11/01/2013	rock	0.064	Very small	412B	1	at fence	From monthly inspection, no exact date
136	2013	11/01/2013	rock	0.900	Small	412B	2	m from fence	From monthly inspection, no exact date
137	2013	11/01/2013	rock	0.108	Small	412B	3	m from fence	From monthly inspection, no exact date
138	2013	11/01/2013	rock	0.012	Very small	412B	1.5	m from fence	From monthly inspection, no exact date
139	2013	11/01/2013	Rock	0.1	Small	412A	0	Small rocks (0.02m <sup>3</sup> each), from larger rock fall at cliff	From monthly inspection, no exact date
140	2013	11/01/2013	Rock	0.600	Small	Marine 1	2.5	m from fence	From monthly inspection, no exact date
141	2013	11/01/2013	Rock	0.008	Extremely small	Boat Club	0	m from fence	From monthly inspection, no exact date
142	2013	11/01/2013	Rock	0.008	Extremely small	Boat Club	0.4	m from fence	From monthly inspection, no exact date



Event	Year	Observation Date	Landslide type	Event Volume	Event Landslide Category	Location (Protection Fence)	Distance from fence (m)		Comments
143	2013	11/01/2013	Rock	0.008	Extremely small	Boat Club	0.25	m from fence	From monthly inspection, no exact date
144	2014	23/03/2014	Debris & rock	132	Very large	CI Club car park	0	Fine particles through fence - 200m beyond fence	Madrassa Landslide
145	2014	24/10/2014	Rock	0.150	Small	408	0	at fence	From monthly inspection, no exact date
146	2014	24/10/2014	Rock	0.064	Very small	408	0.3	m from fence	From monthly inspection, no exact date
147	2014	24/10/2014	Rock	0.090	Very small	408	0.3	m from fence	From monthly inspection, no exact date
148	2014	24/10/2014	Rock	0.027	Very small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
149	2014	24/10/2014	Rock	0.004	Extremely small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
150	2014	24/10/2014	Rock	0.024	Very small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
151	2014	24/10/2014	Rock	0.001	Extremely small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
152	2014	24/10/2014	Rock	0.001	Extremely small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
153	2014	24/10/2014	Rock	0.001	Extremely small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
154	2014	24/10/2014	Rock	0.001	Extremely small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
155	2014	24/10/2014	Rock	0.001	Extremely small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
156	2014	24/10/2014	Rock	0.001	Extremely small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
157	2014	24/10/2014	Rock	0.064	Very small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
158	2014	24/10/2014	Rock	0.060	Very small	Marine 2	2	Assumed distance	From monthly inspection, no exact date



Event	Year	Observation Date	Landslide type	Event Volume	Event Landslide Category	Location (Protection Fence)	Distance from fence (m)		Comments
159	2014	24/10/2014	Rock	0.024	Very small	Marine 2	0	at fence	From monthly inspection, no exact date
160	2014	24/10/2014	Rock	0.027	Very small	Marine 2	0	at fence	From monthly inspection, no exact date
161	2014	24/10/2014	Rock	0.018	Very small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
162	2014	24/10/2014	Rock	0.240	Small	Marine 2	0	at fence	From monthly inspection, no exact date
163	2014	24/10/2014	Rock	0.027	Small	Marine 2	2	Assumed distance	From monthly inspection, no exact date
164	2015	23/01/2015	Rock	0.125	Small	Boat club	1	m from fence	From monthly inspection, no exact date
165	2015	8/10/2015	rock	0.150	Small	412B	1	m from fence	From monthly inspection, no exact date
166	2016	24/03/2016	rock	0.003	Extremely small	Marine 1	1	m from fence	From monthly inspection, no exact date
167	2016	24/03/2016	rock	0.006	Extremely small	Marine 1	1	m from fence	From monthly inspection, no exact date
168	2016	27/05/2016	Rock	0.006	Extremely small	Boat Club	1	m from fence	From monthly inspection, no exact date
169	2016	25/08/2016	Rock	0.008	Extremely small	Marine 1	0	at fence	From monthly inspection, no exact date
170	2016	14/10/2016	Debris	522	Very large	408, 412A/B and Boat Club	0 to -20	m from fence	Basketball Court, 412 and Boat Club Landslides
171	2017	1/06/2017	Debris	2025	Extremely Large	Boat Club, CI Club, 412A/B	10 to -15	m from fence	Boat Club landslide, fence destroyed

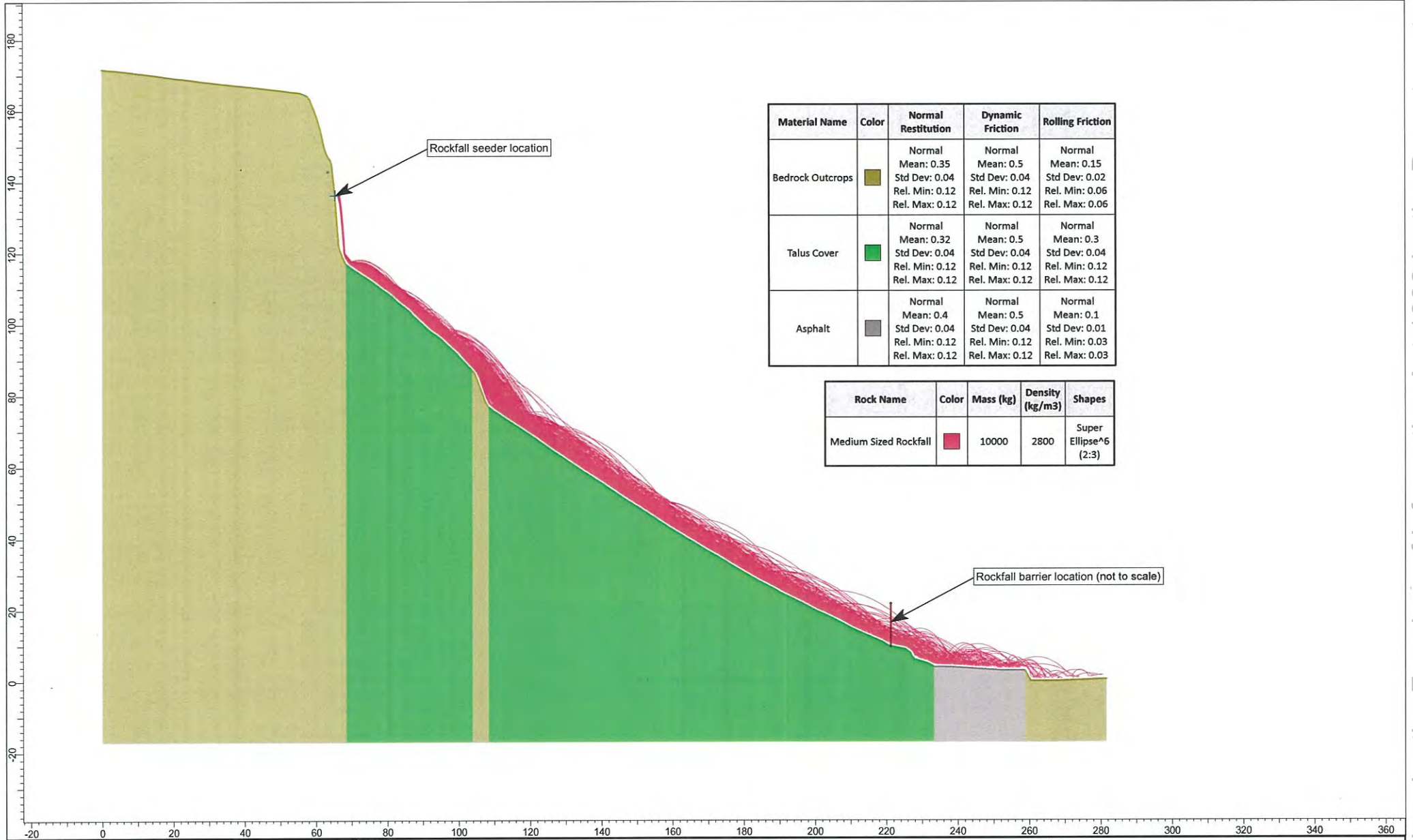
B10

## Appendix C – Results of Rockfall Modelling

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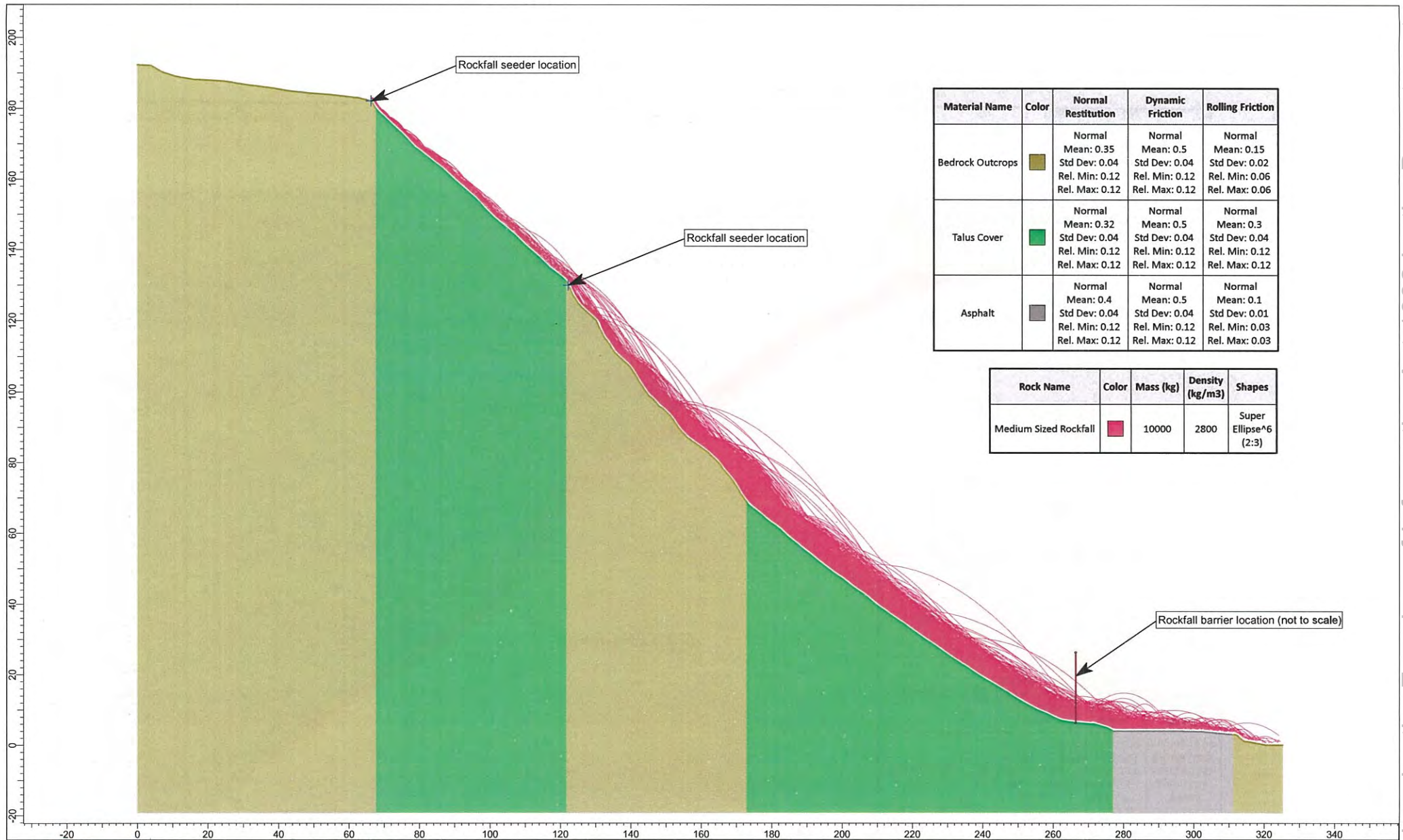


Material Name	Color	Normal Restitution	Dynamic Friction	Rolling Friction
Bedrock Outcrops	<span style="color: #8B873E;">■</span>	Normal Mean: 0.35 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.15 Std Dev: 0.02 Rel. Min: 0.06 Rel. Max: 0.06
Talus Cover	<span style="color: #008000;">■</span>	Normal Mean: 0.32 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.3 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12
Asphalt	<span style="color: #696969;">■</span>	Normal Mean: 0.4 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.1 Std Dev: 0.01 Rel. Min: 0.03 Rel. Max: 0.03

Rock Name	Color	Mass (kg)	Density (kg/m <sup>3</sup> )	Shapes
Medium Sized Rockfall	<span style="color: #DC143C;">■</span>	10000	2800	Super Ellipse <sup>6</sup> (2:3)


	Project		Flying Fish Cove, Christmas Island - Quantitative Landslide Risk Assessment	
	Analysis Description		Section A	
	Drawn By	ICJ	Company	Department of Infrastructure & Regional Development and Cities
	Date	17/07/2018	File Name	Section A - 1999 rockfall event.fal6

ROCFALL\_6\_002



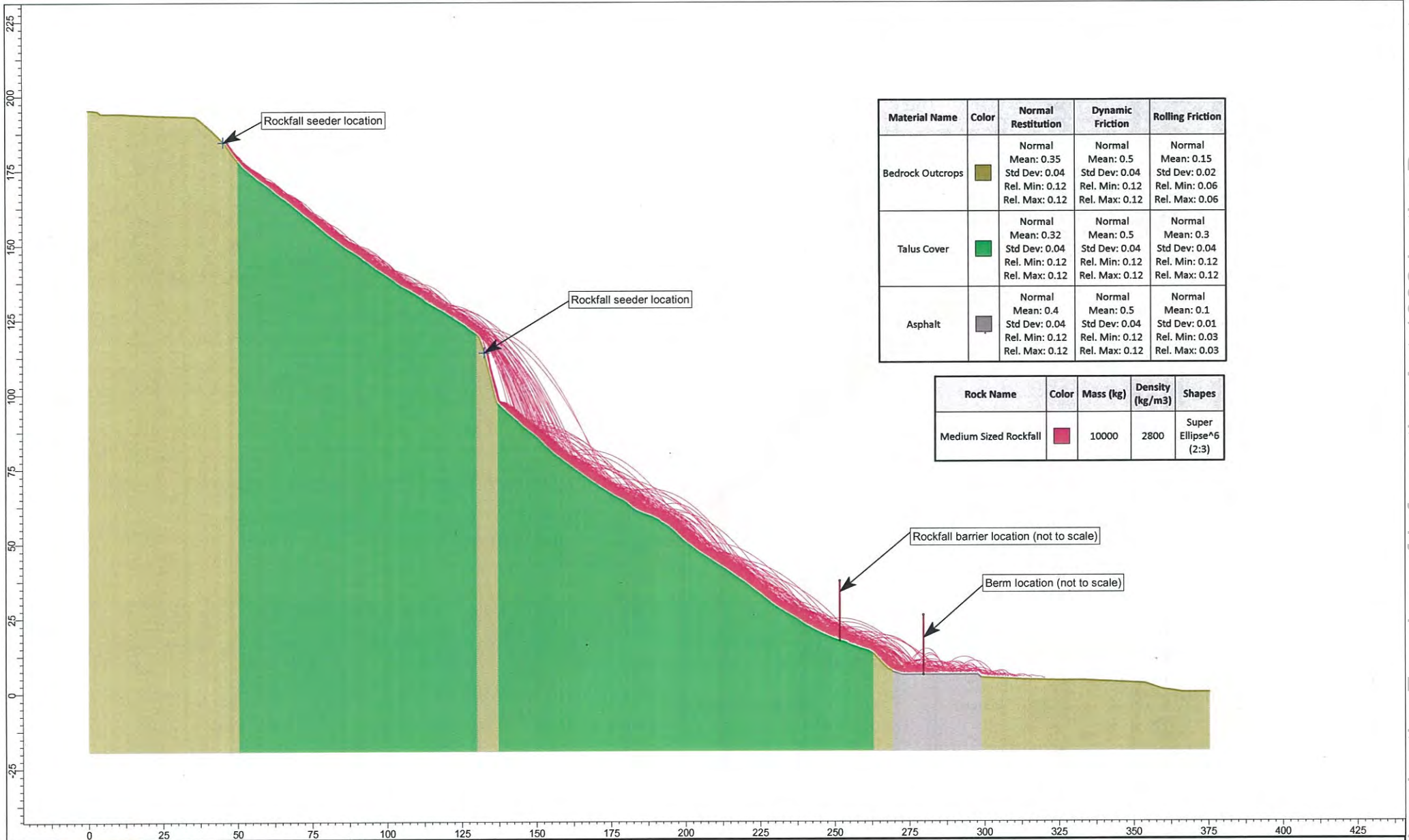
Material Name	Color	Normal Restitution	Dynamic Friction	Rolling Friction
Bedrock Outcrops	<span style="color: #8B4513;">■</span>	Normal Mean: 0.35 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.15 Std Dev: 0.02 Rel. Min: 0.06 Rel. Max: 0.06
Talus Cover	<span style="color: #008000;">■</span>	Normal Mean: 0.32 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.3 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12
Asphalt	<span style="color: #808080;">■</span>	Normal Mean: 0.4 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.1 Std Dev: 0.01 Rel. Min: 0.03 Rel. Max: 0.03

Rock Name	Color	Mass (kg)	Density (kg/m <sup>3</sup> )	Shapes
Medium Sized Rockfall	<span style="color: #DC143C;">■</span>	10000	2800	Super Ellipse <sup>6</sup> (2:3)

	Project	Flying Fish Cove, Christmas Island - Quantitative Landslide Risk Assessment		
	Analysis Description	Section B		
	Drawn By	ICJ	Company	Department of Infrastructure & Regional Development and Cities
	Date	17/07/2018	File Name	Section B.fal6

ROCFALL 6.002

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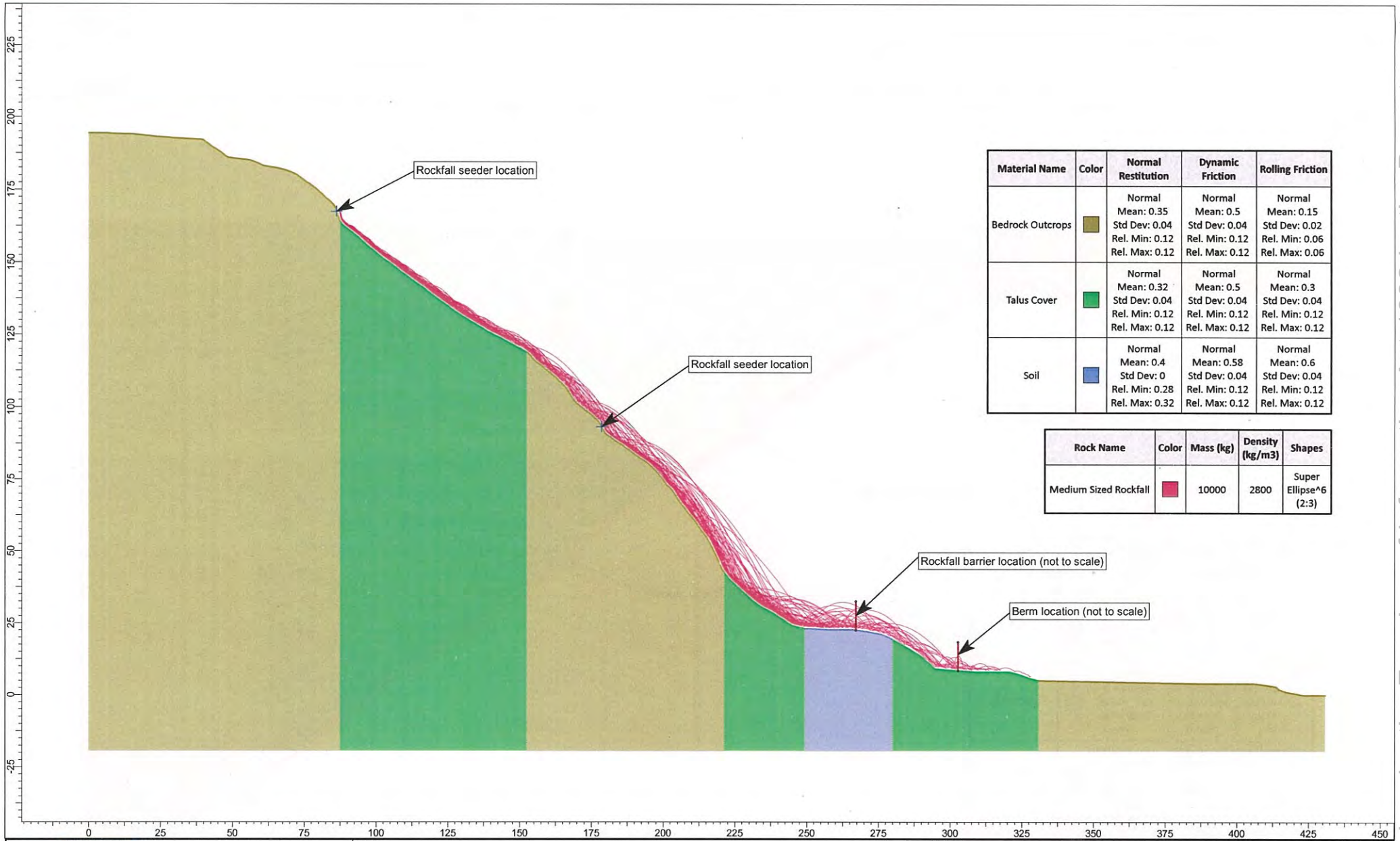


Material Name	Color	Normal Restitution	Dynamic Friction	Rolling Friction
Bedrock Outcrops		Normal Mean: 0.35 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.15 Std Dev: 0.02 Rel. Min: 0.06 Rel. Max: 0.06
Talus Cover		Normal Mean: 0.32 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.3 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12
Asphalt		Normal Mean: 0.4 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.1 Std Dev: 0.01 Rel. Min: 0.03 Rel. Max: 0.03

Rock Name	Color	Mass (kg)	Density (kg/m3)	Shapes
Medium Sized Rockfall		10000	2800	Super Ellipse*6 (2:3)

	Project Flying Fish Cove, Christmas Island - Quantitative Landslide Risk Assessment	
	Analysis Description Section C	
	Drawn By ICJ	Company Department of Infrastructure & Regional Development and Cities
	Date 17/07/2018	File Name Section C.fal6

ROCKFALL 6.002

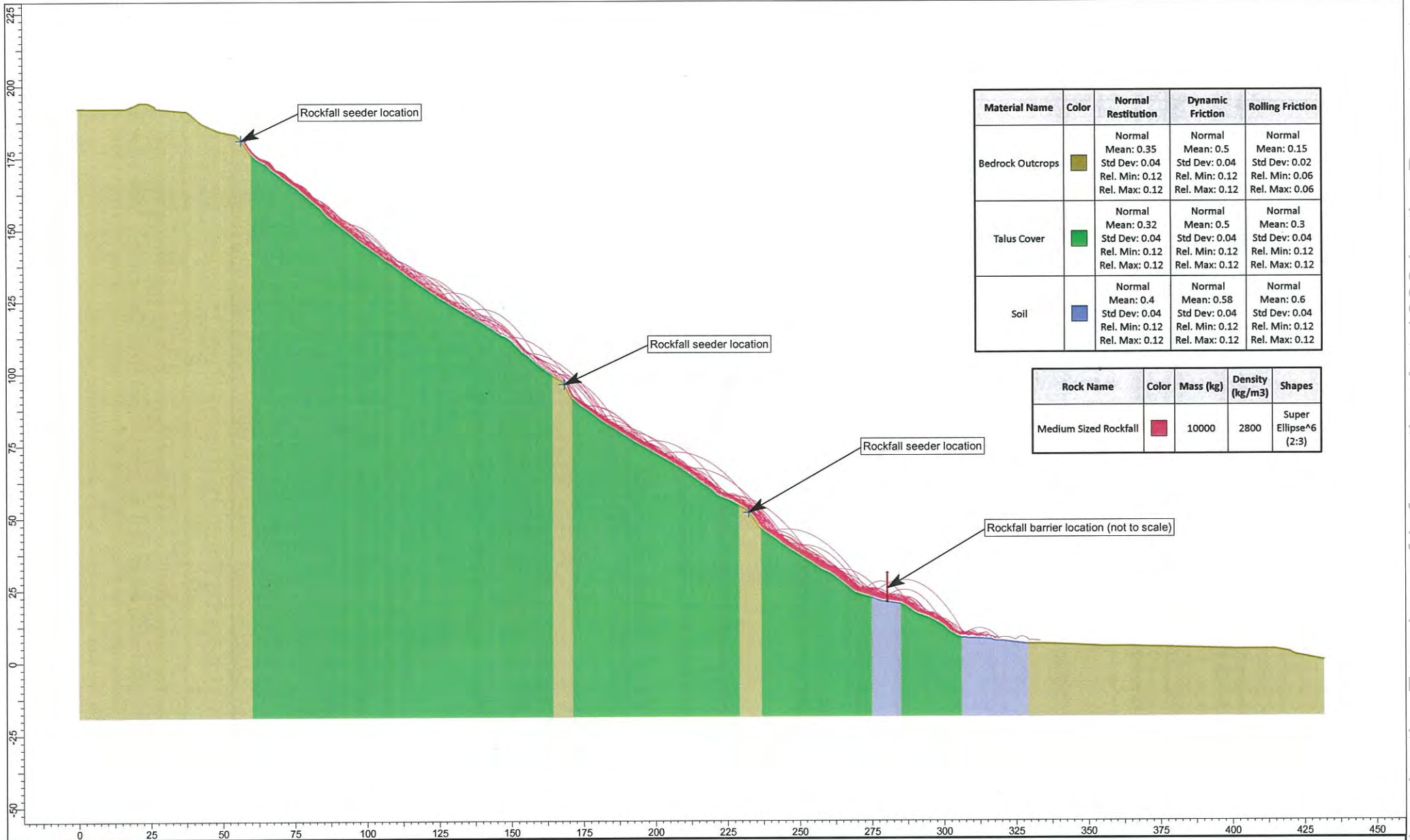


Material Name	Color	Normal Restitution	Dynamic Friction	Rolling Friction
Bedrock Outcrops		Normal Mean: 0.35 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.15 Std Dev: 0.02 Rel. Min: 0.06 Rel. Max: 0.06
Talus Cover		Normal Mean: 0.32 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.3 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12
Soil		Normal Mean: 0.4 Std Dev: 0 Rel. Min: 0.28 Rel. Max: 0.32	Normal Mean: 0.58 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.6 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12

Rock Name	Color	Mass (kg)	Density (kg/m <sup>3</sup> )	Shapes
Medium Sized Rockfall		10000	2800	Super Ellipse*6 (2:3)




Project		Flying Fish Cove, Christmas Island - Quantitative Landslide Risk Assessment	
Analysis Description		Section D	
Drawn By	ICJ	Company	Department of Infrastructure & Regional Development and Cities
Date	17/07/2018	File Name	Section D.fal6

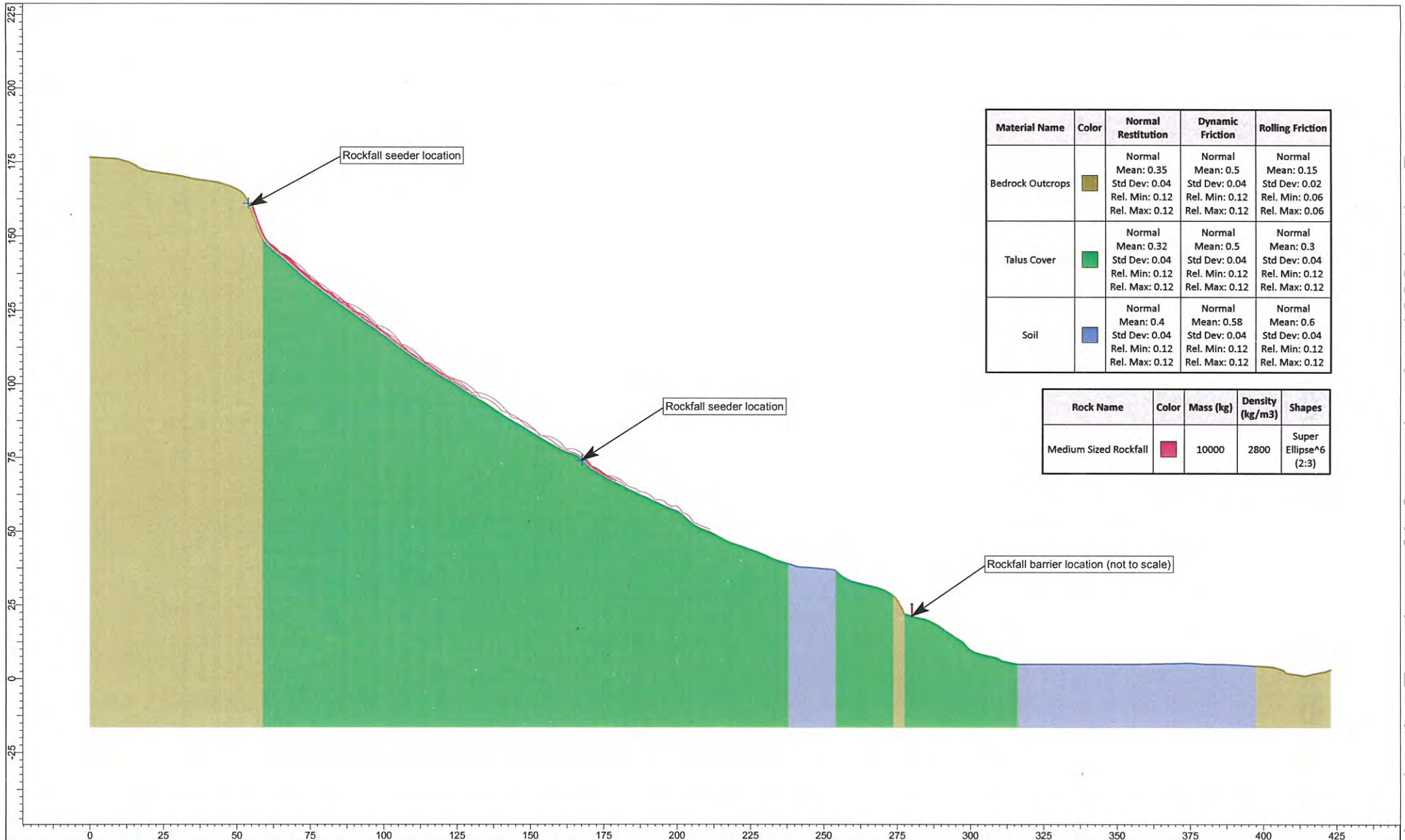


Material Name	Color	Normal Restitution	Dynamic Friction	Rolling Friction
Bedrock Outcrops	Tan	Normal Mean: 0.35	Normal Mean: 0.5	Normal Mean: 0.15
		Std Dev: 0.04	Std Dev: 0.04	Std Dev: 0.02
		Rel. Min: 0.12	Rel. Min: 0.12	Rel. Min: 0.06
Talus Cover	Green	Normal Mean: 0.32	Normal Mean: 0.5	Normal Mean: 0.3
		Std Dev: 0.04	Std Dev: 0.04	Std Dev: 0.04
		Rel. Min: 0.12	Rel. Min: 0.12	Rel. Min: 0.12
Soil	Blue	Normal Mean: 0.4	Normal Mean: 0.58	Normal Mean: 0.6
		Std Dev: 0.04	Std Dev: 0.04	Std Dev: 0.04
		Rel. Min: 0.12	Rel. Min: 0.12	Rel. Min: 0.12

Rock Name	Color	Mass (kg)	Density (kg/m <sup>3</sup> )	Shapes
Medium Sized Rockfall	Red	10000	2800	Super Ellipse <sup>6</sup> (2:3)


	Project		Flying Fish Cove, Christmas Island - Quantitative Landslide Risk Assessment	
	Analysis Description		Section E	
	Drawn By	ICJ	Company	Department of Infrastructure & Regional Development and Cities
	Date	17/07/2018	File Name	Section E.fal6

ROCFALL 6.002



Material Name	Color	Normal Restitution	Dynamic Friction	Rolling Friction
Bedrock Outcrops	Gold	Normal Mean: 0.35 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.15 Std Dev: 0.02 Rel. Min: 0.06 Rel. Max: 0.06
Talus Cover	Green	Normal Mean: 0.32 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.5 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.3 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12
Soil	Blue	Normal Mean: 0.4 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.58 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12	Normal Mean: 0.6 Std Dev: 0.04 Rel. Min: 0.12 Rel. Max: 0.12

Rock Name	Color	Mass (kg)	Density (kg/m3)	Shapes
Medium Sized Rockfall	Red	10000	2800	Super Ellipse^6 (2:3)

	Project Flying Fish Cove, Christmas Island - Quantitative Landslide Risk Assessment	
	Analysis Description Section F	
	Drawn By ICJ	Company Department of Infrastructure & Regional Development and Cities
	Date 17/07/2018	File Name Section F.fal6

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## Appendix D – Risk Assessment Calculations

Released under the Freedom of Information Act 1982 by the Department of Infrastructure, Transport, Regional Development, Communications, Sport and the Arts



## Risk Estimation - AGS (2007)

**LOCATION:** Boat Club Area / carpark  
**CALCULATIONS BY:** A. Hunter  
**DATE:** Monday, 23 July 2018

**CLIENT:** Department of Infrastructure & Regional Development and Cities  
**PROJECT:** Flying Fish Cove, Christmas Island  
**PROJECT No.:** 6137201

HAZARD	ELEMENTS AT RISK		PROBABILITY OF LANDSLIDE OCCURRENCE	SPATIAL PROBABILITY			TEMPORAL PROBABILITY		VULNERABILITY	ANNUAL PROBABILITY OF LOSS OF LIFE (DEATH) OF AN INDIVIDUAL	
	DESCRIPTION	ELEMENT	COMMENTS	ANNUAL	SITE LENGTH	AFFECTED LENGTH	SPATIAL PROBABILITY	WEEKLY EXPOSURE			TEMPORAL PROBABILITY
				$P_{(H)}$	m	m	$P_{(SH)}$	Hours			$P_{(T,S)}$
Medium Rockfall	Individuals in carpark (in open)	-	0.1120	660	1	0.0015	14	0.0833	0.90	1.27E-05	
	Individuals in vehicle	Cars parking in carpark	0.1120	660	5	0.0076	7	0.0417	1.00	3.54E-05	
	Vehicle driving along Jalan Pantai Road (north of traffic lights)	Assume car takes on average 15 seconds to traverse carpark / boat ramp area (one way)	0.1120	660	5	0.0076	0.875	0.0052	0.50	2.21E-06	
Large Rockfall	Individuals in carpark (in open)	-	0.0700	660	1	0.0015	14	0.0833	0.90	7.95E-06	
	Individuals in vehicle	Cars parking in carpark	0.0700	660	5	0.0076	7	0.0417	1.00	2.21E-05	
	Vehicle driving along Jalan Pantai Road (north of traffic lights)	Assume car takes on average 15 seconds to traverse carpark / boat ramp area (one way)	0.0700	660	5	0.0076	0.875	0.0052	0.50	1.38E-06	
Very Large Debris Flow	Individuals in carpark (in open)	People in carpark near retaining wall - if buried	0.0440	660	25	0.0379	14	0.0833	1.00	1.39E-04	
	Individuals in vehicle	Cars parking in carpark - if buried	0.0440	660	25	0.0379	7	0.0417	1.00	6.94E-05	
	Vehicle driving along Jalan Pantai Road (north of traffic lights)	Assume car takes on average 15 seconds to traverse carpark / boat ramp area (one way). Vehicle unlikely to be buried.	0.0440	660	25	0.0379	0.875	0.0052	0.10	8.68E-07	
Extremely Large Debris Flow	Individuals in carpark (in open)	People in carpark near retaining wall - if buried	0.0250	660	50	0.0758	14	0.0833	1.00	1.58E-04	
	Individuals in vehicle	Cars parking in carpark	0.0250	660	50	0.0758	7	0.0417	1.00	7.89E-05	
	Vehicle driving along Jalan Pantai Road (north of traffic lights)	Assume car takes on average 15 seconds to traverse carpark / boat ramp area (one way). Vehicle unlikely to be buried.	0.0250	660	50	0.0758	0.875	0.0052	0.10	9.86E-07	

This page must be read in conjunction with the following report:

Flying Fish Cove, Christmas Island - Quantitative Landslide Risk Assessment. Report Ref: 6137201-5937. July 2018



### Risk Estimation - AGS (2007)

**LOCATION:** Marine Building Area  
**CALCULATIONS BY:** A. Hunter  
**DATE:** Monday, 23 July 2018

**CLIENT:** Department of Infrastructure & Regional Development and Cit  
**PROJECT:** Flying Fish Cove, Christmas Island  
**PROJECT No.:** 6137201

HAZARD	ELEMENTS AT RISK		PROBABILITY OF LANDSLIDE OCCURRENCE	SPATIAL PROBABILITY			TEMPORAL PROBABILITY		VULNERABILITY	ANNUAL PROBABILITY OF LOSS OF LIFE (DEATH) OF AN INDIVIDUAL	
	DESCRIPTION	ELEMENT	COMMENTS	ANNUAL	SITE LENGTH	AFFECTED LENGTH	SPATIAL PROBABILITY	WEEKLY EXPOSURE			TEMPORAL PROBABILITY
				$P_{(H)}$	m	m	$P_{(S-H)}$	Hours			$P_{(T-S)}$
Medium Rockfall	Individuals working in Marine Building	Assume workers are distributed throughout the building	0.1120	660	3	0.0045	40	0.2381	0.80	9.70E-05	
	Individuals working in Federal Police Building	Assume workers are distributed throughout the building	0.1120	660	3	0.0045	17	0.1012	0.80	4.12E-05	
Large Rockfall	Individuals working in Marine Building	Assume workers are distributed throughout the building	0.0700	660	3	0.0045	40	0.2381	0.80	6.06E-05	
	Individuals working in Federal Police Building	Assume workers are distributed throughout the building	0.0700	660	3	0.0045	17	0.1012	0.80	2.58E-05	
Very Large Debris Flow	Individuals working in Marine Building	Assumes large debris flow would cause partial collapse of building and inundate large area with debris.	0.0440	660	70	0.1061	40	0.2381	1.00	1.11E-03	
	Individuals working in Federal Police Building	Assumes large debris flow would cause partial collapse of building and inundate large area with debris.	0.0440	660	8	0.0121	17	0.1012	1.00	5.40E-05	
Extremely Large Debris Flow	Individuals working in Marine Building	Assumes debris flow would cause partial to complete collapse of building and inundate large area with debris.	0.0250	660	70	0.1061	40	0.2381	1.00	6.31E-04	
	Individuals working in Federal Police Building	Assumes debris flow would cause partial to complete collapse of building and inundate large area with debris.	0.0250	660	8	0.0121	17	0.1012	1.00	3.07E-05	

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## Risk Estimation - AGS (2007)

**LOCATION:** Block 413 Area  
**CALCULATIONS BY:** A. Hunter  
**DATE:** Monday, 23 July 2018

**CLIENT:** Department of Infrastructure & Regional Development and Cities  
**PROJECT:** Flying Fish Cove, Christmas Island  
**PROJECT No.:** 6137201

HAZARD	ELEMENTS AT RISK		PROBABILITY OF LANDSLIDE OCCURRENCE	SPATIAL PROBABILITY			TEMPORAL PROBABILITY		VULNERABILITY	ANNUAL PROBABILITY OF LOSS OF LIFE (DEATH) OF AN INDIVIDUAL	
	DESCRIPTION	ELEMENT	COMMENTS	ANNUAL	SITE LENGTH	AFFECTED LENGTH	SPATIAL PROBABILITY	WEEKLY EXPOSURE			TEMPORAL PROBABILITY
				$P_{(H)}$	m	m	$P_{(S-H)}$	Hours			$P_{(T-S)}$
Medium Rockfall	Individuals in carpark (in open) west of Berm 2	-	0.0056	660	1	0.0015	3	0.0179	0.90	1.36E-07	
	Individuals in storage shed behind Block 413	-	0.0056	660	3	0.0045	2	0.0119	0.80	2.42E-07	
	Individuals on basketball court	-	0.0056	660	1	0.0015	2	0.0119	0.90	9.09E-08	
Large Rockfall	Individuals in carpark (in open) west of Berm 2	-	0.0035	660	1	0.0015	3	0.0179	0.90	8.52E-08	
	Individuals in storage shed behind Block 413	-	0.0035	660	3	0.0045	2	0.0119	0.80	1.52E-07	
	Individuals on basketball court	-	0.0035	660	1	0.0015	2	0.0119	0.90	5.68E-08	
Very Large Debris Flow	Individuals in carpark (in open) west of Berm 2	Assumes debris flow would breach berm and flow into carpark area.	0.0440	660	25	0.0379	3	0.0179	1.00	2.98E-05	
	Individuals in storage shed behind Block 413	Debris flows likely to stop prior to or reach the vicinity of sheds and unlikely to cause inundation.	0.0440	660	25	0.0379	2	0.0119	0.05	9.92E-07	
	Individuals on basketball court	Assumes debris flow would breach berm and flow onto basketball court.	0.0440	660	18	0.0273	2	0.0119	1.00	1.43E-05	
Extremely Large Debris Flow	Individuals in carpark (in open) west of Berm 2	Assumes debris flow would breach berm and flow into carpark area.	0.0250	660	50	0.0758	3	0.0179	1.00	3.38E-05	
	Individuals in storage shed behind Block 413	Debris flows likely to stop prior to or reach the vicinity of sheds and unlikely to cause inundation.	0.0250	660	50	0.0758	3	0.0179	0.05	1.69E-06	
	Individuals on basketball court	Assumes debris flow would breach berm and flow onto basketball court.	0.0250	660	18	0.0273	2	0.0119	1.00	8.12E-06	



## Risk Estimation - AGS (2007)

**LOCATION:** Block 409 Area  
**CALCULATIONS BY:** A. Hunter  
**DATE:** Monday, 23 July 2018

**CLIENT:** Department of Infrastructure & Regional Development and Cities  
**PROJECT:** Flying Fish Cove, Christmas Island  
**PROJECT No.:** 6137201

HAZARD	ELEMENTS AT RISK		PROBABILITY OF LANDSLIDE OCCURRENCE	SPATIAL PROBABILITY			TEMPORAL PROBABILITY		VULNERABILITY	ANNUAL PROBABILITY OF LOSS OF LIFE (DEATH) OF AN INDIVIDUAL	
				ANNUAL	SITE LENGTH	AFFECTED LENGTH	SPATIAL PROBABILITY	WEEKLY EXPOSURE			TEMPORAL PROBABILITY
Medium Rockfall	Individuals in carpark (in open) west of Berm 1	-	0.0056	660	1	0.0015	3	0.0179	0.90	1.36E-07	
	Individuals in storage shed behind Block 409	-	0.0056	660	3	0.0045	2	0.0119	0.80	2.42E-07	
Large Rockfall	Individuals in carpark (in open) west of Berm 1	-	0.0035	660	1	0.0015	3	0.0179	0.90	8.52E-08	
	Individuals in storage shed behind Block 409	-	0.0035	660	3	0.0045	2	0.0119	0.80	1.52E-07	



## Risk Estimation - AGS (2007)

**LOCATION:** Madrasa / Shop Area  
**CALCULATIONS BY:** A. Hunter  
**DATE:** Monday, 23 July 2018

**CLIENT:** Department of Infrastructure & Regional Development and  
**PROJECT:** Flying Fish Cove, Christmas Island  
**PROJECT No.:** 6137201

HAZARD	ELEMENTS AT RISK		PROBABILITY OF LANDSLIDE OCCURRENCE	SPATIAL PROBABILITY			TEMPORAL PROBABILITY		VULNERABILITY	ANNUAL PROBABILITY OF LOSS OF LIFE (DEATH) OF AN INDIVIDUAL	
	DESCRIPTION	ELEMENT	COMMENTS	ANNUAL	SITE LENGTH	AFFECTED LENGTH	SPATIAL PROBABILITY	WEEKLY EXPOSURE			TEMPORAL PROBABILITY
				$P_{(H)}$	m	m	$P_{(S,H)}$	Hours			$P_{(T,S)}$
Medium Rockfall	Individuals in Madrasa	Assumes at least one or more individuals are located in the rear half of the building when the building is occupied.	0.1120	660	3	0.0045	9	0.0536	0.80	2.18E-05	
	Individuals in shop	-	0.1120	660	3	0.0045	40	0.2381	0.80	9.70E-05	
	Individuals in cold storage building behind Madrasa	-	0.1120	660	3	0.0045	2	0.0119	0.80	4.85E-06	
Large Rockfall	Individuals in Madrasa	Assumes at least one or more individuals are located in the rear half of the building when the building is occupied.	0.0700	660	3	0.0045	9	0.0536	0.80	1.36E-05	
	Individuals in shop	-	0.0700	660	3	0.0045	40	0.2381	0.80	6.06E-05	
	Individuals in cold storage building behind Madrasa	-	0.0700	660	3	0.0045	2	0.0119	0.80	3.03E-06	
Very Large Debris Flow	Individuals in Madrasa	Assumes debris flow would cause partial or total collapse of rear half of building and inundate large area with debris.	0.0440	660	18	0.0273	9	0.0536	1.00	6.43E-05	
	Individuals in shop	Assumes debris flow would cause collapse of majority of the building and inundate large area with debris.	0.0440	660	7	0.0106	40	0.2381	1.00	1.11E-04	
	Individuals in cold storage building behind Madrasa	Assumes debris flow would cause total destruction of building.	0.0440	660	18	0.0273	2	0.0119	1.00	1.43E-05	
Extremely Large Debris Flow	Individuals in Madrasa	Assumes debris flow would cause total collapse building and inundate large area with debris.	0.0250	660	18	0.0273	9	0.0536	1.00	3.65E-05	
	Individuals in shop	Assumes debris flow would cause total collapse building and inundate large area with debris.	0.0250	660	7	0.0106	40	0.2381	1.00	6.31E-05	
	Individuals in cold storage building behind Madrasa	Assumes debris flow would cause total destruction of building.	0.0250	660	18	0.0273	2	0.0119	1.00	8.12E-06	

This page must be read in conjunction with the following report:  
 Flying Fish Cove, Christmas Island - Quantitative Landslide Risk Assessment. Report Ref: 6137201-5937. July 2018



## Risk Estimation - AGS (2007)

**LOCATION:** Block 403 Area  
**CALCULATIONS BY:** A. Hunter  
**DATE:** Monday, 23 July 2018

**CLIENT:** Department of Infrastructure & Regional Development and  
**PROJECT:** Flying Fish Cove, Christmas Island  
**PROJECT No.:** 6137201

HAZARD	ELEMENTS AT RISK		PROBABILITY OF LANDSLIDE OCCURRENCE	SPATIAL PROBABILITY			TEMPORAL PROBABILITY		VULNERABILITY	ANNUAL PROBABILITY OF LOSS OF LIFE (DEATH) OF AN INDIVIDUAL	
	DESCRIPTION	ELEMENT	COMMENTS	ANNUAL	SITE LENGTH	AFFECTED LENGTH	SPATIAL PROBABILITY	WEEKLY EXPOSURE			TEMPORAL PROBABILITY
				$P_{(H)}$	m	m	$P_{(S,H)}$	Hours			$P_{(T,S)}$
Medium Rockfall	Individuals in carpark behind Block 403	-	0.0112	660	3	0.0045	2	0.0119	0.80	4.85E-07	
	Individuals in Block 403	Assumes an individual will be in a ground floor apartment about 50% of the time.	0.0112	660	3	0.0045	84	0.5000	0.80	2.04E-05	
Large Rockfall	Individuals in carpark behind Block 403	Assumes at least one or more individuals are located in the rear half of the building when the building is occupied.	0.0070	660	3	0.0045	2	0.0119	0.80	3.03E-07	
	Individuals in Block 403	-	0.0070	660	3	0.0045	84	0.5000	0.80	1.27E-05	
Very Large Debris Flow	Individuals in carpark behind Block 403	Assumes debris flow would inundate most of the carpark with debris.	0.0440	660	25	0.0379	2	0.0119	1.00	1.98E-05	
	Individuals in Block 403	Assumes debris flow may reach / strike building only.	0.0440	660	25	0.0379	84	0.5000	0.05	4.17E-05	
Extremely Large Debris Flow	Individuals in carpark behind Block 403	Assumes debris flow would inundate most of the carpark with debris.	0.0250	660	42	0.0636	2	0.0119	1.00	1.89E-05	
	Individuals in Block 403	Assumes large debris flow would inundate part of lower floor of building. Volume of debris reaching building not likely to be sufficient to bury people.	0.0250	660	42	0.0636	84	0.5000	0.10	7.95E-05	

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Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
A	Andrew Hunter	Alison Jennings		Alison Jennings		31/07/18

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